PROCEEDINGS OF PAPERS

UNIVERSITY OF NIŠ
FACULTY OF OCCUPATIONAL SAFETY OF NIŠ
Department of Preventive Engineering
Noise and Vibration Laboratory

"POLYTECHNICA" UNIVERSITY OF TIMISOARA
FACULTY OF MECHANICAL ENGINEERING
Department of Mechanics and Vibration
Noise and Vibration Laboratory

23rd National Conference
4th International Conference

Noise and Vibration

Niš, 17-19, October 2012.
SERBIA

23rd NATIONAL & 4th INTERNATINAL CONFERENCE

NOISE AND VIBRATION



PROCEEDING OF PAPERS

Niš, October 17th - 19th, 2012.

Publisher: *University of Niš, Faculty of Occupational Safety*
For the publisher: *Prof. Ljiljana Živković, Ph. D.*
dean

Editors of proceeding of papers:
Prof. Dragan Cvetković, Ph. D.
Prof. Vasile Marinca, Ph. D.
Prof. Nicolae Herisanu, Ph. D.
Prof. Momir Praščević, Ph. D.

Graphic design and prepress:
Ass. Darko Mihajlov, M. Sc.
Rodoljub Avramović

Printout: "M Kops Center" Niš

No. of copies: 200

ISBN: 978-86-6093-042-4

REVIEWS:
All papers have been reviewed by members of scientific committee

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

534.83(082)
62-752(082)
614.872(082)
628.517(082)

NATIONAL Conference Noise and Vibration (23 ; 2012 ; Niš)
Proceeding of Papers / 23rd National & 4th International Conference Noise and Vibration ; [organizers University of Niš, Faculty of Occupational Safety of Niš, Department of Preventive Engineering [and] "Politechnica" University of Timisoara, Faculty of Mechanical Engineering, Department of Mechanical Engineering ; editors Dragan Cvetković ... et al.]. - Niš : Faculty of Occupational Safety, 2012 (Niš : M Kops Center). - 305 str. : ilustr. ; 30 cm

Tekst štampan dvostubačno. - Tiraž 200. - Bibliografija uz svaki rad.

ISBN 978-86-6093-042-4
1. International Conference Noise and Vibration (4 ; 2012 ; Niš) 2. Faculty of Occupational Safety (Niš)
a) Бука - Зборници b) Вибрације - Зборници
COBISS.SR-ID 194076684

ORGANIZER

University of Niš
Faculty of Occupational Safety of Niš
Department of Preventive Engineering
Noise and Vibration Laboratory
www.znrfak.ni.ac.rs

"Politechnica" University of Timisoara
Faculty of Mechanical Engineering
Department of Mechanical Engineering
Noise and Vibration Laboratory
http://www.mec.upt.ro

AUSPICE

Ministry of Education, Science and Technological Development Republic Serbia
www.mpn.gov.rs

GENERAL SPONSOR

Brüel & Kjær

www. bksv.com

CONFERENCE REVIEW

1st Yugoslav Conference	Belgrade	1978
2nd Yugoslav Conference	Belgrade	1979
3rd Yugoslav Conference	Belgrade	1980
4th Yugoslav Conference	Belgrade	1981
5th Yugoslav Conference	Belgrade	1982
6th Yugoslav Conference	Belgrade	1983
7th Yugoslav Conference	Belgrade	1984
8th Yugoslav Conference	Belgrade	1985
9th Yugoslav Conference	Belgrade	1986
10th Yugoslav Conference	Belgrade	1987
11th Yugoslav Conference & 1st International Conference	Belgrade	1988
12th Yugoslav Conference	Belgrade	1989
13th Yugoslav Conference	Niš	1991
14th Yugoslav Conference & 2nd International Conference	Niš	1993
15th Yugoslav Conference & 3rd International Conference	Niš	1995
16th Yugoslav Conference with international participation	Niš	1998
17th Yugoslav Conference with international participation	Niš	2000
18th Yugoslav Conference with international participation	Niš	2002
19th Conference with international participation	Niš	2004
20th Conference with international participation	Tara	2006
21st Conference with international participation	Tara	2008
22nd Conference with international participation	Niš	2010
23rd Conference and 4th International Conference	Niš	2012

PROGRAM COMMITTEE

Prof. Dragan Cvetković, Ph. D. - chairman
Prof. Vasile Marinca, Ph. D. - co-chairman
Prof. Petar Pravica, Ph. D.
Prof. Giangiacomo Minak, Ph. D.
Prof. Marek Grzybowski, Ph. D.
Assoc. Prof. Miloš Manić, Ph. D.
Prof. Pantele Chelu, Ph. D.
Prof. Nicolae Herisanu, Ph. D.
Prof. Vasile Bacria, Ph. D.
Prof. Liviu Beriteu, Ph. D.
Prof. Tihomir Trifonov, Ph. D.
Prof. Koleta Zafirova, Ph. D.
Ass. Prof. Nikola Holeček, Ph. D.
Ass. Prof. Valentina Golubović-Bugarski, Ph. D.
Ratko Uzunović, Ph. D.
Prof. Slobodan Gajin, Ph. D.
Prof. Nikola Lilić, Ph. D.
Prof. Ljiljana Živković, Ph. D.
Prof. Nenad Živković, Ph. D.
Prof. Predrag Kozić, Ph. D.
Prof. Zoran Perić, Ph. D.
Assoc. Prof. Zoran Petrović, Ph. D.
Assoc. Prof. Zlatan Šoškić, Ph. D.

ORGANISITION COMMITTEE

Assoc. Prof. Momir Praščević, Ph. D. - chairman
Prof. Nicolae Herisanu, Ph. D. - co-chairman
Prof. Vasile Marinca, Ph. D.
Prof. Dragica Milenković, Ph. D.
Assoc. Prof. Jasmina Radosavljević, Ph. D.
Ass. Prof. Miomir Raos, Ph. D.
Ass. Branko Radičević, MSc
Ass. Nebojša Bogojević, MSc
Ass. Darko Mihajlov, MSc

CONTENT

INTRODUCTION LECTURE

Miriam Weber 11
Quiet Urban Areas: repositioning local noise policy approaches – questioning visitors on soundscape and environmental quality

Zlatan Šoškić , Zoran Petrović, Dragan Cvetković, Srđan Rusov 15
Development of methodologies and means for noise protection of urban areas – project description

1ST SESSION

Momir Praščević, Dragan Cvetković, Darko Mihajlov, Nikola Holeček 21
The acoustic zoning - a comparasion of legislation and experiences in Italy and Serbia

Boris Mihaylov, Milcho Georgiev 29
Environmental noise mapping, action planning and noise monitoring in Bulgaria

Jovana Đilas 33
Traffic noise action planning in agglomerations reduction potentials based on German good practice example

Predrag Petrović, Rade Mirović, Martin Jakscn, Manferd T. Kalivoda 39
Noise monitoring in zone construction of a new Sava bridge in Belgrade - „Bridge on Ada "

Emil Živadinović, Sanja Bijelović, Nataša Dragić, Milka Popović, Siniša Milosević, Živojin Lalović 45
Environmental noise as the hazard in the environment of the city of Novi Sad

Darko Mihajlov, Momir Praščević, Dragan Cvetković 49
An analysis of the environmental noise levels on the territory of the city of Niš

Marina Pljakić, Branko Radičević, Jelena Tomić, Zvonko Petrović 59
Analysis of systematic measurements of noise in cities

Mirjana Mladenović 63
Calibration of sound level meter

2ND SESSION

Henk Wolfert 67
Managing industrial noise

Branko Radičević, Zoran Petrović, Slobodan Todosijević, Zvonko Petrović 71
Design of noise protection of industrial plants - case study of a plywood factory

Zoran Petrović, Branko Radičević, Zvonko Petrović, Nebojša Zdravković 77
Design of noise protection in urban areas - case study of an elementary school

Aleksandar Gajicki, Ružica Ilić 83
Noise protection measures in the territory of Novi Sad during reconstruction, modernization and construction of the Stara Pazova - Novi Sad double track railway line

Vladan Grković, Milan Kolarević, Zvonko Petrović, Miomir Vukićević 89
Morphology of modular traffic noise barriers

Milan Kolarević, Vladan Grković, Miomir Vukićević, Mišo Bjelić 95
Configuration of modular noise barriers

Mišo Bjelić, Miomir Vukićević, Aleksandra Petrović, Marina Pljakić 101
Analysis of materials used for production of noise protection barriers

Snežana Radulović Jevremović, Vladimir Babić 105
Analysis of traffic noise problem in stages of road design

3RD SESSION

Nicolae Herişanu, Vasile Marinca 109
Periodic solutions for the nonlinear oscillator $\ddot{x} + (1 + \dot{x}^2)x = 0$

Vasile Marinca, Nicolae Herişanu 113
Optimal variational method for antisymmetric, constant force oscillator

Vasile Marinca, Remus-Daniel Ene 117
Optimal homotopy perturbation method for nonlinear oscillators with a fractional-order restoring force

Goran Radoičić, Miomir Jovanović 121
The extreme dynamic state of main members of frame supporting structure

Slavko Zdravković, Dragan Zlatkov, Biljana Mladenović, Milovan Stanojev, Sandra Šaković 127
Tsunami – water seismic waves

Tomislav Igić, Slavko Zdravković, Biljana Mladenović, Predrag Petronijević, Sandra Šaković 131
Characteristic sources of seismic vibrations

Milovan Stanojev, Slavko Zdravković, Dragan Zlatkov 137
Brontides - acoustic phenomena during earthquakes

Dragan Zlatkov, Slavko Zdravković, Nikola Romić 141
Vibration of seismic waves through soil

4TH SESSION

Ranko Antunović 145
Advanced methods of vibration diagnostics

Marko Bek, Nikola Holeček, Igor Emri 149
Viscoelastic damping elements for vibration reduction

Valentina Golubović-Bugarski, Aleksandar Borković 153
Dynamic load testing of bridges

Snežana Jovanović, Zdravko Banjac 159
Development testing of vibrations on the helicopter with automatic weapon

Mirza Hadzimujović, Sandra Šaković, Biljana Mladenović 167
Vibrations of railway as a cause of noise due to railway transport

Branislav Aleksandrović, Rajko Radonjić, Aleksandra Janković 171
Researching the effects of motorcycle's vibrational processes on safe drive

Rajko Radonjić, Aleksandra Janković, Branislav Aleksandrović, Dragoljub Radonjić 179
Excitating vehicle's vibrations from the road surface

Ninoslav Zuber 185
Roller elements bearing vibrodiagnostics

Ninoslav Zuber 193
Application of artificial inteligence methods in automated vibrodiagnostics of rotating machines in mining industry – a case study

Aleksandar Đuric, Snežana Jovanović 203
Application of vibrodiagnostic in testing off-road vehicles

5TH SESSION

Tihomir Trifonov, Georgi Dimkov, Ivan Simeonov, Rosen Dzhakov 209
Use of conformal mapping method for visualization and classification of acoustic signals

Nikola Holeček 213
Noise control of integrated refrigerator and freezer domestic appliance

Nicolae Herisanu, Vasile Bacria 221
Investigation of the acoustic field on the platform of a concrete preparartion station

Jelena Tomić, Nebojša Bogojević, Bojan Tatić, Zlatan Šoškić 225
Design and implementation of on−line database of noise sources

Vasile Bacria, Nicolae Herisanu 229
Decreasing the noise generated by the road transportation means

Aleksandar Mićović, Vladimir Popović, Snežana Jovanović 233
Acoustic testing inside cabin and passenger space of off-road vehicle Land Rover Defender 110 Soft Top

Sandra Šaković, Predrag Petronijević, Milovan Stanojev 237
Analysis of the noise from railway traffic

Ljubiša Vasov, Slobodan Gvozdenović, Olja Čokorilo, Petar Mirosavljević, Branimir Stojiljković 243
Elements of aircraft noise management

Bojan Tatić, Nebojša Bogojević 249
Analysis of the noise generated by helicopters with various numbers of the propellers on the main rotor

Ljubomir Lukić, Mirko Đapić, Dušica Lukić, Aleksandra Petrović 255
Aspects of design of power transformers for noise reduction

Aleksandra Petrović, Ljubomir Lukić, Milan Kolarević, Dusica Lukić 263
Noise measurements of the power transformers

6TH SESSION

Milanka Vasić, Marina Jordanović, Ljiljana Jevremović 269
Noise control in buildings regarding the conversion purposes - new use for old buildings

Ana Petelj, Miodrag Hadžistević, Aco Antić, Janko Hodolič 275
Application of the reverberation time formulations in ordinary rooms

Jelica Tošić
Analysis of the problems and mistakes in scientific paper titles 279

Mirjana Sovilj, Ljiljana Dobrijević
Examining auditory perception and auditory memory by application of PHS and electrophysiological researches 283

Ljiljana Stošić, Ljiljana Blagojević, Suzana Milutinović
Perception of and attitudes to urban noise among citizens of Nis (Serbia) 289

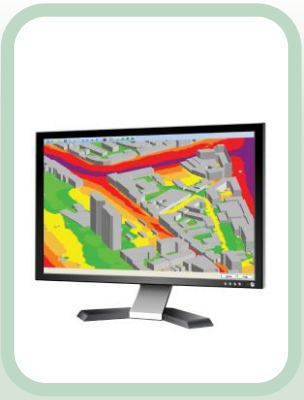
Dragoslav Ilić
Noise-induced hearing loss – the plague of the new millennium 293

PAPER OF STUDENTS

Marija Marković, Nikola Odalović
Supporting construction of sound barriers 299

Dragana Sladoje , Bojana Velickovic
Technical solutions for different types of barrier top 303

BRÜEL & KJÆR
SOUND & VIBRATION
MEASUREMENTS









We help our partners and customers
measure and manage
the quality of sound and vibration
in products and enviroment

With more than 90 sales offices or local agents,
we provide immediate and comprehensive
customer support



Contact your local
sales representative:

RMS d.o.o.
Partizanske avijacije 12/3
11070 Novi Beograd, Srbija
Tel.: +381(0)11 2280 951
Fax: +381(0)11 2280 751
www.rms.rs

Brüel & Kjær

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

QUIET URBAN AREAS: REPOSITIONING LOCAL NOISE POLICY APPROACHES – QUESTIONING VISITORS ON SOUNDSCAPE AND ENVIRONMENTAL QUALITY

Miriam Weber[1]

[1] DCMR Environmental Protection Agency Rijnmond, the Netherlands, miriam.weber@dcmr.nl

Abstract - *Current practices about selection, assessment and management of quiet urban areas in European countries appear to be fragmented and widely varying, or even lacking. Although the EU Directive 49/2002/CE on Environmental Noise (commonly abbreviated END) and national (nature, noise or urban planning) policy instruments set requirements on the delineation and management of these areas of 'good acoustic environment'. Various studies and the European Commission's implementation review of the END illustrated that many competent authorities experienced difficulties in the delineation and characterization of quiet (urban) areas. Nevertheless there are examples of good practice from some European cities and e.g. the COST Action on Soundscape and the ISO working group on soundscape. In Rotterdam and nature areas in the province of South Holland some of these current approaches have been applied and adjusted. This paper presents preliminary results regarding one of the assessment tools, i.e. questioning visitors on soundscape and other qualities of the quiet (urban) area.*

1. INTRODUCTION

Soundscape research is gaining much interest from a diverse range of scholars and researchers. International conferences address the topic in technical sessions and academic journals regularly publish newest insights from all over the world.

An ISO working group started working since some years on standardized approaches and recently proposed to define soundscape as ''perception of the acoustic environment as perceived by people in that place, in context''. The next phase in the working group's activities will consist of standardization of soundscape research and methodologies [1]. As Lam et al. [2] state, knowledge of which soundscapes people prefer and what affects their preferences is instrumental in defining soundscapes of ''good quality''. The EU Environmental Noise Directive is not very clear and specific on these definitions, although recognizing the need to protect areas of good acoustic quality. Reasons given are to provide retreat from urban stress and to recuperate psychologically. Research of, for example, the Dutch Health Council [3] has underlined these positive, health and stress-reducing, effects of green and quiet areas.

The Environmental Noise Directive distinguishes quiet urban areas and quiet natural areas. Abundant research has been published on urban public spaces or quiet urban areas. Examples are Schulte-Fortkamp [4] with a specific focus on the local experts, and Adams et al. [5] on noise policy and sustainable urban soundscapes, and Payne et al. [6]. In addition, there is an increasing number of conference proceedings and papers on soundscape research in urban areas describing the approaches applied. Examples are Weber [7] on methodologies for assessing soundscapes of parks in Rotterdam, Nilsson and Berglund [8] in Sweden, Brambilla and Maffei [9] in Italy.

In this paper the main focus will be on the methods applied for assessing the soundscape relying on peoples' perception. Although physical measurements, e.g. measurements of (psycho)acoustic indicators, are required as well, there is specifically a need for discussions on field survey approaches.

2. QUIET AREAS: METHODS APPLIED

2.1 Studies applying soundscape approaches

DCMR has conducted various studies on quiet areas and the perception of the soundscape and environmental quality. In spring 2011 three parks in Rotterdam have been assessed, varying in seize from 1 ha - 2 ha to more than 200 ha. Methodological lessons learned have been used for improving the subsequent study in two nature areas in the province of South Holland at the end of 2011. These nature areas, open meadows situated near cities, are 2.700 ha and 12.700 ha in seize.

The aim of these studies was to characterize and assess quiet areas and recommend methodologies for future research. Although local government in the Netherlands lacks practical experience regaring quiet urban areas, Dutch regional governments (in Dutch: provinces) have implemented policies regarding quiet areas already decades ago. The Dutch Environmental Management Act requires competent authorities to delineate and protect quiet natural areas (in Dutch: stiltegebieden), comprising at least the following types of areas: (i) protected nature areas, and (ii) wetlands as designed by the Ramsar Convention. Quiet natural areas should have a certain seize, tranquility and added value for recreation or fauna. Finally, the quiet natural area are delineated guaranteeing noise levels not higher than 40 dB Lden. However, despite these 'regulative requirements' limited practical experience nor tools are available on *assessing* and *characterizing* natural quiet areas, nor on evaluating soundscape perception.

2.2 Methodology

In our studies human perception of the soundscape of the selected areas is assessed based upon acoustical data as well as human perception response data in situ. Responses were measured by questionnaires, with approximately 50 interviews successfully completed per site and thus approximately 250 respondents in total.

The data obtained in the field survey were analyzed using Statistical Package for the Social Science (SPSS) for Windows version 17.0. Statistical analyses consisted of Pearson, Spearman and ANOVA analyses. Aim of these analyses is to define relationships between human preferences and perceptual variables using correlation and stepwise regression analysis, similar to Lam et al [2]. A secondary aim of these analyses is to assess which questions, answers and coding mechanisms prove to be practical in usage *and* provide sufficient scientific evidence to base conclusions.

2.3 Questionnaire

The questionnaire applied in the field survey is based upon work from COST Action Soundscape [10]. The structure of the questionnaire is as follows:

(i) general questions on: reason, frequency, duration, companionship, day of week, time of day of the visit;
(ii) questions on sound(scape): characterization of soundscape, audibility of sound sources, annoyance from sound sources, pleasantness of sound sources, acoustic quality;
(iii) questions on the environmental surroundings, the natural area: environmental quality, characterization of the area e.g. tranquility, natural quality, safety, pleasantness;
(iv) questions on personal data: male/female, age, education, occupancy, zip code;
(v) questions on living conditions: distance between home and natural area, acoustic quality at home, annoyance from sound sources at home

Most of these questions have closed, easy to code, answer categories or scales ranging from 1 to 5 (so-called Lickert scale).

3. RESULTS

3.1 Soundscape quality assessment

Berglund et al. [11] defined verbal descriptions of soundscape qualities to be applied in, for example, soundwalks. The verbatim proposed are the following:

Unpleasant - pleasant
Uneventful - eventful
Chaotic - quiet
Boring - exciting

In assessing the acoustic environment in urban parks in Rotterdam[6] these descriptions have been translated into Dutch and applied in interviewing citizens. During that study respondents seemed to be distracted and misled by some verbal descriptions, such as the Dutch translation ''opwindend'' of ''exciting'' and the dichotomy of uneventful – eventful. Therefore in the study in the quiet natural areas the description ''spannend'' instead of ''opwindend'' was used, as well as ''kalm'' instead of ''stil'' (for quiet). The respondents in this study felt more comfortable with these descriptions of the acoustic environment.

As Figure 1 illustrates, the descriptions 'weinig afwisselend' and 'afwisselend' (uneventful – eventful), depicted with a 180 degree edge, have a strong negative correlation, which makes this a strong pair of verbal descriptions. In addition, the verbatim have high descriptive value, as can be concluded from the length of the lines (the longer, the more descriptive the question or variable is). This is the case for both pilot study areas.

We found similar negative correlations for the descriptions 'hinderlijk' and 'plezierig' (literally translated in English this would read annoying – pleasant) and 'chaotisch' and 'kalm' (chaotic – calm) although the latter pair is less correlated (the edge is less than 180 degrees). Interestingly, both pairs of verbal descriptions are more descriptive in the parks than in the nature areas. But nevertheless, the verbatim seem applicable and statistically sound in both types of quiet areas.

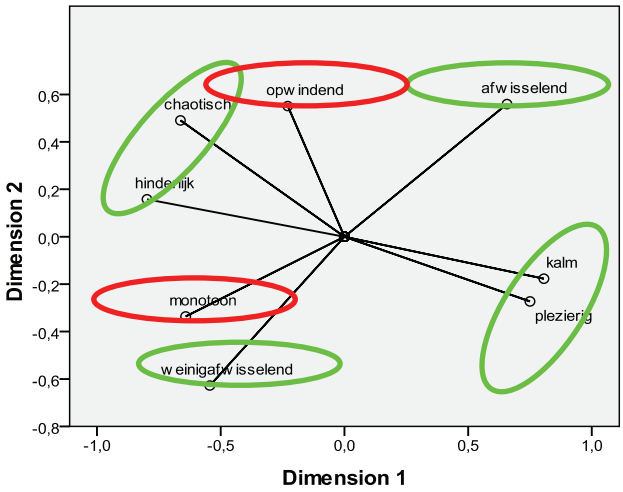


Fig. 1 *Categorical Principal Component Analyses of soundscape qualities in quiet urban areas*

3.2 Sound source category assessment

An objective of maintaining the quality of the soundscape in natural areas is human appreciation, enjoyment and positive effects on stress and other negative health effects. In questioning users of these areas preferred sounds, in contrast to the frequently applied, ISO standardised question on noise annoyance, sounds of moving water, sounds of nature, and sounds of other people. The same line of argumentation might be applied for quiet urban areas, as recent studies indicate that these areas can function as a refuge for daily stress and area to relax, reflect or have some physical exercise.

Respondents in the study areas were asked to indicate whether specific sound sources were audible during the visit of the area. Sound sources applied are the following: (i) traffic sounds, (ii) mechanical sounds, (iii) human sounds, and (iv) nature sounds. Note, no qualification of the audible sounds is requested in this question.

The studies showed that respondents in the parks indicated that both traffic as well as nature sounds were audible, and to a lesser account human sounds. The relatively high score on nature might be an indicator for the perception of the soundscape, as will be discussed in the next section (3.3 Acoustic environment). The respondents in the nature area indicate that specifically nature sounds were audible, although traffic sounds were recognized as well. The difference in audibility between these two sound source categories is, not surprisingly, larger than in the urban areas.

3.3 Acoustic environment assessment

In order to assess perception of the afore mentioned sound sources, the respondents were asked to indicate whether certain sound sources were considered annoying and/or pleasant (in two separate, closed questions ranking from 1 (do not agree at all) to 5 (agree fully).

Some interesting preliminary conclusions can be drawn from these analyses. First, in the parks in Rotterdam we found a more complex and scattered picture. Although in general we can conclude that most sound sources are not correlated regarding pleasantness and annoyance caused. In correlating these sound sources with soundscape quality descriptions, the following picture underlines the complexity (see Figure 2). For example, traffic sounds correlate significantly with the soundscape quality descriptions 'pleasant' and 'calm'. Statistical cross checking is in line with this conclusion, as Kendall's tau-b shows significant correlation of ,356 for traffic sounds and pleasantness. Until now, we were not able to find an explanation based upon our empirical data.

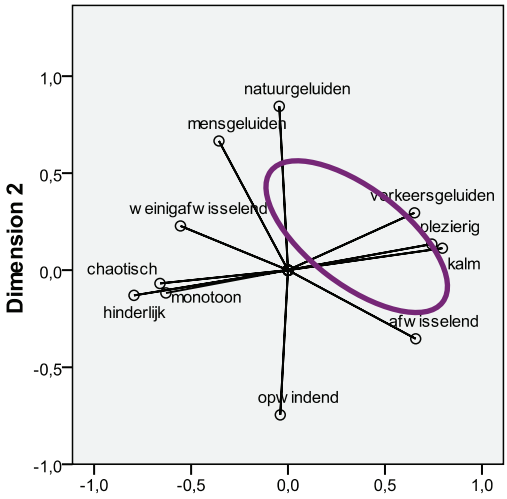


Fig. 2 *Categorical Principal Component Analyses of traffic sound sources and soundscape qualities in quiet urban areas*

Second, considering discriminative power of the various sound sources used in the questions on pleasantness and annoyance we see differences for both types of quiet areas. In the parks discriminative sound sources (the longer lines) are the following: music (both annoying and pleasant); airplane (pleasant); water (pleasant); animals (pleasant); 'citysounds' (pleasant); road traffic (annoying); people (annoying) and scooters (annoying).

In the nature areas the following discriminative sound sources were found: people, children and water which were all relevant in the questions on annoying and pleasant. And finally, water and birds were highly discriminative regarding annoyance. Note, a discriminating variable is not similar to having a high score on this question. Thus, for example, water and birds, which we often assume as pleasant sounds, are highly discriminative in the question on annoying sounds. This means that most respondents gave this question a similar score (and probably stating that these sounds are not annoying at all). On the other hand, we see very limited discrimination for construction noise in the parks (see red circle). This is surprisingly, as during the field survey a lot of construction work was going on and the student conducting the interviews personally noted this sound during all interviews. Despite audibility of the sound, in the range of other sound sources construction sounds were found, in this survey, of limited interest.

In sum, from this assessment we might conclude that the following sound sources should – at least – be incorporated in the questionnaire, that is road traffic, scooters, music, people (and children), water, birds, and in an urban surrounding 'city sounds'.

3.4 Appreciation assessment

The questionnaire comprised questions on the overall quality of the natural area as well; after the acoustic/soundscape questions. Variables such as cleanliness, safety, natural features, visual appearance and tranquility were included, and were scored on a Lickert scale from 1 (fully disagree) to 5 (fully agree).

From these analyses, again, some interesting conclusions can be drawn. First, no correlation is found between cleanliness/safety/pleasantness with the overall appreciation of the nature areas nor its soundscape. Significant correlations regarding these nature areas, though, are found between visual appreciation and tranquility, and between appreciation of the area, sound quality and natural features.

Second, in the parks correlations, though not surprisingly, differ from the nature areas. In the parks significant correlations are found regarding visual appreciation and natural features. A preliminary conclusion might be that specifically in urbanized areas these natural features are more appreciated and positively valued than in nature areas (where these natural features are abundantly available and regarded 'a condition sine qua non' for these areas). In this line of reasoning, the significant correlation between soundscape quality and tranquility perfectly fits. All variables, in addition, being highly discriminative.

Our preliminary conclusions, based upon both field surveys, are that in quiet urban areas soundscape (in this case 'balanced audibility' of specific sound source categories, supportive to a perception of tranquility) and natural features are crucial features for the appreciation of its characteristics and the (positive) perception of the area's acoustic and environmental climate. Whereas in nature areas, specifically tranquility (as characterization of the area's soundscape) and natural features are required for guaranteeing overall appreciation of these areas by its users.

4. CONCLUSIONS

During the next months field survey data will be combined and evaluated with the data from the acoustic measurements. In this future analysis we will have to pay specific attention to possible differences in appreciation and perception of the natural areas by the different ‘’users’’. This fits the approach promoted by Brigitte Schulte-Fortkamp[12] claiming that ‘’local experts are those people in action that live in a certain area under scrutiny and provide their expertise e.g. through evaluation processes such as sound walks and different kind of open interviews. [This] will give a focus for the analysis of the acoustical as well as qualitative data.[..] The attitude and the listener’s expectations and experiences are significant parameters which have to comprehend the different perceptions and evaluations with regard to specific stimuli completely. Moreover the knowledge people have concerned the area they are living in is of most importance.’’

The results of the study will be evaluated regarding the approach applied and further improvements will be implemented in the methodology as well as flow into the several international initiatives such as the QUADMAP LIFE+ project, COST Action on Soundscape and the ISO working group on soundscape.

REFERENCES

[1] Ö. Axelsson, “The ISO 12913 series on soundscape: An update, May 2012”, *proceedings Acoustics 2012 Hong Kong*, 2012.

[2] K.C. Lam, A.L. Brown, L. Marafa and K.C. Chau, “Human preference for countryside soundscape”, *Acta Acustica united with Acustica*, vol. 96, pp. 463-471, 2010.

[3] Gezondheidsraad, *Stille gebieden en gezondheid (Quiet areas and health)*, 2006.

[4] B. Schulte-Fortkamp, “The tuning of noise pollution with respect of the expertise of people’s mind”, *proceedings InterNoise,* 2010.

[5] M. Adams, T. Cox, G. Moore, B. Croxford, M. Refaee and S. Sharples, “Sustainable soundscapes: noise policy and the urban experience”, *Urban Studies*, vol. 43(13), pp. 2385-2398, 2006.

[6] R. Payne, P. Devine-Wright, K.N. Irvine, “People’s perceptions and classifications of sounds heard in urban parks: semantics, affect and restoration”, *proceedings InterNoise,* 2007.

[7] M. Weber, “The soundscape of quiet urban parks in Rotterdam: assessment and review of research approaches”, *proceedings InterNoise*, 2011.

[8] M.E. Nilsson and B. Berglund, “Soundscape quality in suburban green areas and city parks”, *Acta Acustica United with Acuistica*, vol. 92(6), pp. 903-911, 2006.

[9] G. Brambilla and L. Maffei, “Responses to noise in urban parks and in rural areas”, *Acta Acustica United with Acuistica*, vol. 92(6), pp. 881-886, 2006.

[10] A.M. Reyes Muller, *Soundscape: people, mobility and landscape*, COST STSM Scientific Report, 2010.

[11] B. Berglund and M.E. Nilsson, “On a tool for measuring soundscape quality in urban residential areas”, *Acta Acustica united with Acustica*, vol. (92)6, pp. 938-944, 2006.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

DEVELOPMENT OF METHODOLOGIES AND MEANS FOR NOISE PROTECTION OF URBAN AREAS – PROJECT DESCRIPTION

Zlatan Šoškić[1], Zoran Petrović[1], Dragan Cvetković[2] and Srđan Rusov[3]

[1] University of Kragujevac, Faculty of Mechanical Engineering Kraljevo, Serbia, soskic.z@mfkv.kg.ac.rs
[2] University of Nis, Faculty of Occupational Safety
[3] University of Belgrade, Faculty of Transport and Traffic Engineering

Abstract - *The project "Development of methodologies and means for noise protection of urban areas" is national project financed by Ministry of Education and Science of Republic of Serbia with the goal to provide technical support to implementation of noise protection strategy established by Serbian government through a set of laws and regulations. The project comprises three groups of activities: 1) development of methodologies and software support for estimation of exposition to noise 2) development of laboratories for acoustic characterization of objects and 3) design of modular means for noise protection. The project is realized in period 2011−2014 by Serbian universities from Kragujevac, Niš and Belgrade, and with support of Serbian industry and local governments. The paper presents project plan and organization, as well as the performed activities and the obtained results.*

1. INTRODUCTION

The last decade of the XX century and the first decade of the XXI century have seen harmonized efforts of policy makers and researchers in European Union with the goal to establish a common strategy for combatting noise and to develop means for its implementation. The strategy is expressed through a set of documents based on the European Directive on the Assessment and Management of Environmental Noise or Environmental Noise Directive (2002/49/EC) from June 2002 [1]. Under this directive, as a first step in the strategy, member states were obliged to produce noise maps of the major roads, railways, airports and industrial activity sites as well as of large agglomerations by 30th of June, 2007. Noise maps are intended to describe the environmental noise levels caused by the previously mentioned sources in terms of the harmonized noise indicators L_{den} and L_{night}. From these noise levels, other indicators such as the total number of seriously annoyed residents may be derived. This information was to be submitted to the European Commission and made public. The next step of the strategy is drafting of Noise Action Plans, sets of measures for managing the noise issues and effects, including the reduction of noise if necessary. The Noise Action Plans are to be based on the noise−mapping results, drawn by competent authorities with consultation of general public on matters of priorities.

The adopted strategy, though, requested research work in order to provide for technical basis for implementation of the strategy. The research work was carried out through series of national and EU projects, like FP5 project "Harmonoise" [2], FP6 project "Imagine" [3] and FP7 project "Silence" [4]. The project "Harmonoise" developed common European methodology for estimation of the influence of noise to human agglomerations and common European reference and engineering models for description of sound propagation. The methodology is applied for development of model for prediction of road and railway traffic noise. The efforts of the project "Harmonoise" are complemented by the research work in the project "Imagine" that, following the same methodology and sound propagation model, improved the existing noise prediction models for road and railway traffic and developed common European models for prediction of influence of aircraft and industrial noise. The main goal of the project "Silence" was development of methodologies for drawing of Noise Action Plans.

As a part of its overall effort to harmonize policies and legislation with EU, Republic of Serbia has established national strategy for noise protection and provided relevant legislative framework consisting of a set of laws and regulations presented in the Table 1. However, implementation of the national strategy requires development of an appropriate institutional and technical infrastructure, which does not exist at the moment: majority of the measures prescribed by the regulations is still not supported by existence of the relevant accredited institutions and research groups, noise protection means available at market and adequate software support. With the aim to solve some of the technical problems connected with the development of the institutional and technical infrastructure, in July 2010 Serbian universities from Kragujevac, Niš and Belgrade proposed to the Serbian Ministry of Education and Science a project entitled "Development of methodologies and means for noise protection of urban areas". The proposal was accepted in December 2010.

This paper describes the concept of the project and the main results achieved in the period 2011−2012.

Table 1 *Serbian legislative framework considering environment noise protection*

Category	Legal act	Explanation
Laws	Law on environmental noise protection of Republic of Serbia (Official Gazette of Republic of Serbia , No. 36/2009 and 88/2010)	Relevant for topics of subjects in charge for environment noise protection, means and conditions for environment noise protection, measurement of environmental noise, access to information about noise, surveillance and other topics of relevance for environment and health protection
Regulation	Regulation on noise indicators, limiting values and methods for estimation of noise indicators, annoyance and detrimental effects of noise (Official Gazette of Republic of Serbia , No. 75/2010)	Determines environment noise indicators, limiting values, methods for estimation of noise indicators, annoyance and detrimental effects of noise to human health
Guidelines	Guidelines on methodology for determination of acoustical zones (Official Gazette of Republic of Serbia, No. 72/2010)	Determines in details methodologies for determination of acoustical zones.
	Guidelines on methods for noise measurements, contents and scope of noise measurement report (Official Gazette of Republic of Serbia, No. 72/2010)	Determines in details methods for noise measurements, contents and scope of noise measurement report
	Guidelines on methodology for design of action plans (Official Gazette of Republic of Serbia, No. 72/2010)	Determines in details methodology for design of action plans for environment noise protection.
	Guidelines on contents and methods of strategic noise mapping and their public presentation (Official Gazette of Republic of Serbia, No. 80/2010)	Determines in details contents and methods of strategic noise mapping as well as public presentation of the maps.
	Guidelines on conditions and documentation for expert organization for noise measurements (Official Gazette of Republic of Serbia, No. 72/2010)	Determines conditions that an expert organization for noise measurements has to fulfill, but also documentation that has to be submitted with application for authorization.
Standards	Serbian standard ISO 1996-1 (Official Gazette of Republic of Serbia, No. 72/2010)	Acoustics–Description, measurement and estimation of environment noise-Part 1: Basic quantities and procedures of estimation
	Serbian standard ISO 1996-2 (Official Gazette of Republic of Serbia, No. 72/2010)	Acoustics- Description, measurement and estimation of environment noise-Part 2: Estimation of environmental noise level
Other	Manual for environment noise measurements (http://www.ekoplan.gov.rs/srl/upload-centar/dokumenti/razno/uputstvo_za_merenje_buke.pdf , 2011)	The manual describes procedures for environmental noise measurements for noise monitoring and individual noise measurements in noise measurements area.

PROJECT DESCRIPTION

Goals and objectives

The goal of the project is to provide technical support to implementation of national strategy for protection from environmental noise through provision of:

- Certified facility for characterization of noise sources;
- Development of software support for local noise mapping and modeling;
- Design of modular noise protection means;

This goal is intended to be reached through achievement of the following objectives:

1. Carrying out a study on dominant noise sources in urban areas in Serbia; the study is to provide the basis for further directions of the action in course of the project;
2. Design of the database for description of urban noise sources; the database will be used as the source of data for local noise mapping and modeling;
3. Construction of reverberation chamber and anechoic chamber and accreditation of the research and testing facility;
4. Development of software modules for noise modeling capable of calculation of noise level generated by multiple sources in presence of multiple barriers and in various environments.;
5. Study on state–of–the–art of noise protection means, which will be further used as the basis for design of noise protection means;

6. Design of modular barriers for noise protection

Besides, the project intends to further facilitate basic research in the field of applied acoustics through enhancing and stimulating studies in the following research fields:

- Modeling of acoustic fields of noise sources;
- Active noise protection (both construction methods and emission methods)

Project plan

The project activities are organized in three workpackages that contain research and development activities, one workpackage that contains promotion activities and one workpackage that contains project management activities.

The first R&D workpackage, entitled "Development of methods for estimation of exposition to noise", gathers activities that are concerned with measurement, mapping and prediction of noise levels in urban areas. The main activities of the workpackage are:

1.1. Study of dominant noise sources in Serbian urban areas

1.2. Design of national database for industrial, traffic and public service noise sources

1.3. Presentation of GIS data in noise maps

1.4. Development of software modules for noise mapping and modeling

The second R&D workpackage, entitled "Development of materials and means for reduction of noise emission", gathers activities concerned with measurement of noise emission of individual noise sources, as well as with active and passive methods for reduction of the emitted noise. The main activities of the workpackage are:

2.1. Study of methods for active noise protection

2.1.1. Study of construction methods for active noise protection

2.1.2. Study of emission methods for active noise protection

2.2. Construction of reverberation chamber and semi−anechoic chamber

2.3. Study of absorption methods and materials for noise protection

2.3.1. Study of noise absorption by plant fields

2.3.2. Study of noise absorption by waste materials

2.3.3. Study of noise absorption of Serbian construction materials

The third R&D workpackage, entitled "Design of means for noise protection", gathers activities concerned with design of modular barriers and other means for protection of urban areas from emitted noise. The main activities of the workpackage are:

1. Study of contemporary concepts in design of noise protection means
2. Conceptual design
3. Design of the selected noise protection solutions
4. Construction and testing of prototypes
5. Design of technologies, auxiliary tools and packages

The three workpackages thus represent a harmonized and complete set of actions with intentions to provide technical means for revealing places with intensive noise exposition, determining the causes of the noise and, according to possibilities, to reduce noise emission or to protect the endangered area from the emitted noise.

Following the policy of the Ministry of Education and Science of Republic of Serbia, the project comprises also intensive project promotion activities, oriented both towards expert and general public. Promotion activities oriented towards expert public include participation in national and international conferences, publication of journal papers and organization of seminars for professionals in field of environment protection. Promotion activities for general public include development of website of the project, information on major project results in media and participation in science popularization events. All the activities are grouped in one very diverse and loosely organized workpackage.

Finally, the project demands organization and control measures, as well as reporting activities, which are gathered in one workpackage dedicated to project management. This workpackage includes weekly activity team meetings, monthly or bi−monthly meetings of teams within research organizations and meetings of the whole project team each six months. According to the rules of Serbian Ministry of Education and Science, two kinds of reports are submitted annually, one concerning research results, and the other concerning financial management topics.

Considering the dependences between the project activities, limitation in human and material resources and conditions posted by Serbian Ministry of Education and Science, the project duration is four years, and it will be carried out in period 1st of January 2011 – 31st of December 2014.

Organization

For the achievement of project objectives are engaged available human and material resources. Human resources consist of team of researchers from University of Kragujevac (Faculty of Mechanical Engineering Kraljevo), University of Niš (Faculty of Occupational Safety) and University of Belgrade (Faculty of Traffic Engineering). The researchers provide expertise and experience in following research areas:

- noise and vibration
- measurement techniques
- software development
- project management

The team is organized in three research groups

- Group for methodologies of noise studies
- Group for design of noise protection means
- Group for software development and support

Group for methodologies of noise studies concerns with development of methodologies for measurement of noise emission, methodologies for modeling of noise propagation and methodologies for estimation of effects of noise exposition in urban areas. The group consists of experts in noise and vibration and it is responsible for activities from

the first and the second workpackage except for the activities 1.2 and 1.4 in the first workpackage.

Group for design of noise protection means concerns with design of noise protection means for active and passive noise protection. It consists of mechanical engineers and is responsible for activities in the third research workpackage.

Group for software development and support concerns with design and implementation of software tools for noise field modeling and noise measurements, with development of databases for noise modeling and project management purposes, as well as with development of the website and other promotion tools. It consists of electrical engineers and is responsible for project activities 1.2 and 1.4 of the first workpackage, as well as activities from workpackages concerned with promotion, dissemination and project management.

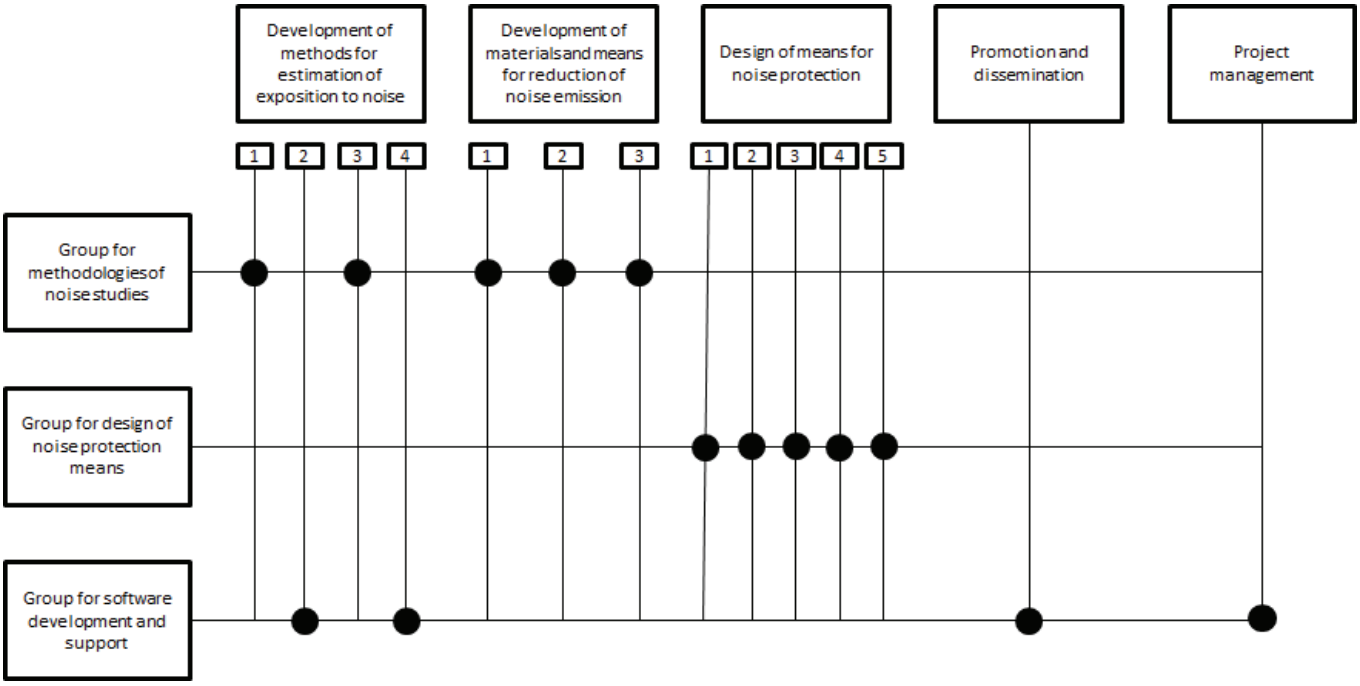


Fig.1: *Relations between work breakdown structure and organization breakdown structure*

The complete team consists at the moment of sixteen researchers. Eleven of them are mechanical engineers (nine experienced researchers and two junior researchers), four are electrical engineers (two experienced and two junior researchers), while one is traffic engineer.

The matrix that shows the dependence between project organization structure and work breakdown structure is shown in the Fig.1.

The direct costs of the project are around 220,000 EUR. The budget breakdown is as follows:

- Personnel costs 140,000 EUR
- Equipment costs 60,000 EUR
- Travel, consumables and other costs 20,000 EUR

The project budget is provided by Ministry of Science of Republic of Serbia (80%), financial contribution of Municipalities of Niš and Kraljevo, as well as by contribution in material and work by companies "ABS Minel" from Belgrade and "Korali" from Kraljevo.

PROJECT RESULTS

The project "Development of methodologies and means for urban noise protection" passed through its initial phase in 2011, and in the first half of 2012 are obtained some final and some important intermediate results.

Workpackage 1: Development of methods for estimation of exposition to noise

The activity "Study of dominant noise sources in Serbian urban areas" is performed through contacts with local governments (local ecology action teams). They were asked to fulfill a form describing the concepts of noise monitoring including methodology of noise measurements, timing of measurements, selection criteria, number and disposition of measurement points. Besides, the form requested description of results of noise monitoring through rough distribution of measurement results expressed as percentage of measurement points where noise limits are exceeded. Noise monitoring is performed in twenty Serbian cities, and the response is obtained from the four of them, while the data are gathered from the websites of six more cities. The data showed great deal of variety between the methodologies applied in the cities, and the results of the study are presented in this conference [5]. The further work within the activity depends on the activities of Agency for noise protection of Republic of Serbia that still needs to define its policy and role in noise protection.

Additional work on the activity is performed through noise measurements on specific urban objects. For different reasons, the noise measurements were focused on crossroads (with the idea to test different models of crossroad noise) and elementary schools (by request of local governments as project participants). The results obtained in these tasks are presented at this conference [6][7].

The activity “Design of national database for industrial, traffic and public service noise sources” resulted in development of on–line relational database which is available via internet [8]. The database enables detailed description of point sources and line sources by storing data about sound power, spectra and spatial distribution of emitted noise. For complex noise sources, the database provides possibility for storing mathematical relationships which describe emitted noise. The access to the database data is possible through standard SQL queries, which is suitable for development of software tools and components for noise mapping. Read rights are granted without limitation, whereas rights for writing the data are granted only to developers at the moment. The database has interface in Serbian language. While the database is active, the task of inserting data that describe data sources is still to be performed. However, the task has permanent character, and the manner in which it will be performed remains to be determined. The structure and implementation of the database is described in a paper presented at this conference [9].

Work on the activity “Presentation of GIS data in noise maps” started through a case–study of noise protection of area around major overpass in Kraljevo. While the measurements and calculations of noise field are performed, the task is late because of delay of implementation of GIS in Serbian municipalities.

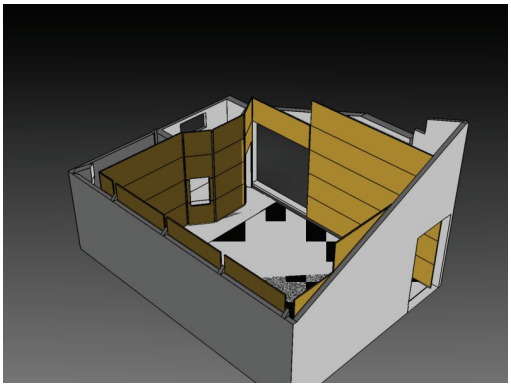


Fig.2 *Three-dimensional model of room for reverberation and semi-anechoic chamber*

The activity “Development of software modules for noise mapping and modeling” comprises development of modules for modeling of sound propagation and modules for interfacing the software modules with end users and with GIS data systems. At the moment is finished module for calculation of noise field created by multiple sources and screened by multiple barriers. The noise field may have any shape, and barriers are considered vertical. The sources are considered point–like, and while linear sources may be simulated as series of point–like sources, the module for calculation of noise field with linear noise sources. Present interface is provisional and while it provides complete access to functionality of the noise field modeling module, it is textfile–oriented and not so easy to use.

Workpackage 2: Development of materials and means for reduction of noise emission

The most intensive activity performed in the second workpackage was “Construction of reverberation chamber and semi−anechoic chamber”. The activity comprises extensive work and has several tasks. Faculty of Mechanical Engineering Kraljevo provided the premises for the facility, a large room with volume 198.7 m^3, and the largest distance 10.8 m (upper limit for the respective volume is 11.1 m). Threedimensional model of the room is shown in Fig. 2. The room is adapted by provision of insulation layer on the roof (plywood), walls (plaster) and floor (epoxide). By thin concrete walls the room is separated into control room, reverberation chamber and semi-anechoic chamber. The chambers may be joined through a window that can be up to 3 meters wide and up to 3 meters high. After the adaptation, the walls and roof of the reverberation room are equipped with cork insulation plates and reflection panels. Current activities are concerned with provision of measurement equipment suitable for measurement of sound emission and absorption, which is going to be used in research and development of noise protection means. The tasks of testing and adjustment of the facilities, as well as the task their accreditation, still remain to be performed.



Fig.3 *Reverberation chamber facility with control room*

The activity “Study of methods for active noise protection” is in its initial phase. The team decided to study the topic on the example of noise control and protection in the case of power transformers for electrical energy distribution. Such choice is made according to the interest expressed by the company "ABS Minel" that manufactures power transformers. However, the financial problems of the company caused decrease of the interest for participation in the research, which significantly reduced work on the activity and shifted focus of the project towards interests of other participants in the project. However, initial contacts with power distribution company from Kraljevo are made, and a selection of objects which should be monitored is performed, so that the research work may be continued in the later phase of the project.

The activity “Study of absorption methods and materials for noise protection” has not been started yet; its beginning is planned after the test facilities are finished.

Workpackage 3: Design of means for noise protection

The third research workpackage depends on the activities performed in the second workpackage because serious development of noise protection means is not possible without acoustic research facilities.

However, the preparatory activity "Study of contemporary concepts in design of noise protection means" of the workpackage is finished, and the activity "Conceptual design" is underway. The work was focused on studies of noise barriers and the results are presented at this conference [10] [11].

Workpackage 4: Promotion and dissemination

The widest promotion tool of the project is its website [12]. Written in Serbian, it presents basic information about project, list of project activities, list of project results and project news. English version of the project website should have shorter form, and it is not expected to be available this year.

Project results are presented to expert public in form of 10 papers published in international and national journals and 30 articles presented at seven international and one national conference. The project is also presented through invited lecture at seminar "Communication, electronics and information technologies" organized in June 2012 in Bansko (Bulgaria).

The most important dissemination event was seminar on noise protection held on 27th of December 2011 at Faculty of Mechanical Engineering Kraljevo. The seminar was held for young researchers and environment protection specialists from local governments with the following topics:

- Physical, physiological and psychological basis of noise studies,
- Noise measurements and characterization,
- Industrial noise,
- Traffic noise,
- Urban noise modeling.

CONCLUSION

The paper presented the goals, concept and organization of the project "Development of methodologies and means for urban noise protection". The project, which started at the beginning of 2011, is closing to the end of the second year of work, and achieved the most important goal of establishing technical basis for design and application of noise protection means. The course of events so far confirmed that the project plan was realistic, so it can be expected that the project will achieve its ultimate goal to support implementation of strategy for reduction of noise pollution in Serbia.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to Serbian Ministry of Education and Science for support through project TR37020.

REFERENCES

[1] "Directive 2002/49/EC of the European Parliament and the Council of June 2002", Official Journal of the European Communities, 2002.

[2] http://cordis.europa.eu/fetch?ACTION=D&CALLER=PROJ_IST&QM_EP_RCN_A=57829

[3] http://www.imagine-project.org

[4] http://www.silence-ip.org

[5] Marina Pljakić and Branko Radičević, “Analysis of systematic measurements of noise in cities”, Proceedings of 23rd national and 4th international conference “Noise and Vibration”, Niš, 17-19 October 2012 (to be published)

[6] Zoran Petrović and Branko Radičević, “Design of noise protection in urban areas-case study of an elementary school “,Proceedings of 23rd national and 4th international conference “Noise and Vibration”, Niš, 17-19 October 2012 (to be published)

[7] Branko Radičević and Zoran Petrović, “Design of noise protection of industrial plants-case study of a plywood factory”, Proceedings of 23rd national and 4th international conference “Noise and Vibration”, Niš, 17-19 October 2012 (to be published)

[8] www.mfkv.kg.ac.rs/dbnoise

[9] Jelena Tomić, Zlatan Šoškić, Bojan Tatić and Nebojša Bogojević, “Design and implementation of on-line database of noise sources”, Proceedings of 23rd national and 4th international conference “Noise and Vibration”, Niš, 17-19 October 2012 (to be published)

[10] Milan Kolarević, Vladan Grković, Miomir Vukićević and Mišo Bjelić, "Analysis of criteria in process of design of sound barriers", Proceedings of 23rd national and 4th international conference “Noise and Vibration”, Niš, 17-19 October 2012 (to be published)

[11] Vladan Grković, Milan Kolarević, Zvonko Petrović and Miomir Vukićević, "Morphology of modular traffic noise barriers", Proceedings of 23rd national and 4th international conference “Noise and Vibration”, Niš, 17-19 October 2012 (to be published)

[12] www.mfkv.kg.ac.rs/urbanoise

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

THE ACOUSTIC ZONING - A COMPARASION OF LEGISLATION AND EXPERIENCES IN ITALY AND SERBIA

Momir Praščević[1], Dragan Cvetković[1], Darko Mihajlov[1], Nikola Holoček[2]

[1]University of Nis, Faculty of Occupational Safety, Serbia, e-mail: momir.prascevic@znrfak.ni.ac.rs
[2] Gorenje d.d., Environmental Protection College Velenje, Slovenia, nikola.holecek@gorenje.si

Abstract - *The acoustic zoning is a fundamental tool to manage and plan to use of the territory taking into account the noise pollution. The priority aim of the acoustic zoning is to achieve a correct and accurate interpretation of urban planning characteristics of the different city areas, through preliminary analysis, regarding the city planning tools, road network of the city, the traffic regulations, the displacement of the different activity on the territory (recreation, habitation, business etc.). The comparison of the noise mapping with the acoustic zoning plan points out the critical area where the limits issued by the legislation are exceeded and actions to reduce the noise are needed. The acoustic zoning is mandatory for municipalities as a necessary instrument in order to be able to proceed with the effective environmental noise pollution monitoring and assessment. The different methodologies of acoustic zoning have been used in EU countries. In this paper, a comparison of legislation and experiences in acoustic zoning in Italy and Serbia will be given.*

1. INTRODUCTION

The general public has become aware that many of the benefits of living in modern cities are illusory. They now know that each advance in the speed or convenience of transport or in the application of power to reduce physical effort is usually accompanied by a reduction in the quality of the environment.

Population density and industrialization cause the accumulation of waste products that pollute the environment. Environmental noise has been included because it is a major factor in reducing the pleasure of living in modern cities.

Noise pollution is a growing problem. The growth of noise pollution is directly linked to the development of cities and industry.

The ideal solution would be to eliminate of excessive noise at the source or at least on the propagation paths. However, until the technology is sufficiently advanced to achieve this at reasonable cost or people are ready to abandon the comforts and amenities that come with life in the modern cities, the solution can be the proper planning of the city territory.

Planning must take into account the trends in industrial growth, living conditions and transport needs with the aim of predicting the future environment and ensuring that any changes are beneficial.

The acoustic zoning, which is a method of delineating areas with particular requirements, is a logical step in planning to achieve the necessary reconciliation between the desired comfort of living in the cities and the noise source. When combined with a means for defining restrictions or specifying compatible land usages, it provides a rational solution to an otherwise intractable problem.

The acoustic zoning is a fundamental tool to manage and plan to use of the territory taking into account the noise pollution. The comparison of the noise mapping with the acoustic zoning plan points out the critical area where the limits issued by the legislation are exceeded and actions to reduce the noise are needed.

2. ACOUSTIC ZONING METHODOLOGY

Acoustic zoning means the classification of city territory in zones with homogenous environmental noise levels. The priority aim of the acoustic zoning is to achieve a correct and accurate interpretation of urban planning characteristics of the different city areas, through preliminary analysis, regarding the city planning tools, road network of the city, the traffic regulations, the displacement of the different activity on the territory (recreation, habitation, business etc.).

In addition, the aim of acoustic zoning is to prevent the deterioration of areas in which acoustic pollution is not evident and to improve conditions in those found to have noise levels that produce negative effects on public health.

In addition, it aims to constitute a reference tool for the correct planning of new urban development areas.

Acoustic zoning is mandatory for municipalities as a necessary instrument in order to be able to proceed with the effective environmental noise pollution monitoring, even though phased in gradual steps. It will thus be possible to obtain a reference picture to understand which areas should be protected, which of them have acceptable noise levels, which of them are noise-polluted, where the development of noisy activities can be permitted, and where it is necessary to foresee noise control measures.

From the operative standpoint, the phases preparatory to acoustic zoning can be summed:

- the initial step consists of an analysis of the city territory, after which the preliminary acoustic zoning plan is drawn up, followed in an almost parallel manner by the environmental noise measurements procedure;
- lastly, from analysis of the measurements and preliminary acoustic zoning plan, the final acoustic zoning plan can be determined.

In order to draw up the acoustic zoning plan, it is necessary to obtain and examine in detail many documents. A primarily important aspect is the analysis of the general city plan (city-plan utilization zones) in order to ascertain the actual correspondence between planned uses and actual uses.

It is particularly important to investigate location of:

- hospitals;
- schools;
- parks;
- protected areas;
- acoustically important craft activities;
- acoustically important commercial activities;
- significant industrial plants; and
- road infrastructure.

In fact, careful on-the-spot investigations often reveal, considerable discrepancies between the existing general city plan with relative variants and the real development of the territory concerned.

There are two main approaches for the acoustic zoning and for the identification and evaluation of the different areas:

- the qualitative approach;
- the quantitative approach.

The qualitative approach is based on the direct and in-depth analysis of the characteristics of the territory involved in the acoustic zoning, based on city-planning scheme.

The quantitative approach is based on a computation of a set of parameters and indexes able to characterize the territory analyzed.

Two main factors determine the number and spacing of acoustic zones, the ease with which normal activities and land uses can be subdivided into noise categories and the degree of certainty with which noise exposure can be evaluated or predicted

It would be ludicrous to designate zones at either 1 dB or 20 dB spacing. The first would assume great predictive accuracy combined with a fine graduation in usage classification while the second would assume that our knowledge of future noise exposure and levels to suit particular activities is most inexact

Sufficient research data exists to indicate that transport noise could be predicted within a tolerance of ± 5 dB and this figure also represents a reasonable compromise for controlling industrial noise Present measuring systems are within this range and changes in subjective response to noise are observed for variations below this limit.

3. ACOUSTIC ZONING LEGISLATION

3.1 Italian legislation

Acoustic zoning was introduced by Italian degree DPCM 1/3/91 [1], then it has been confirmed by Framework Law on Environmental Noise 447/95 [2] and DPCM 14/11/97 [3].

Italian decree DPCM 1/3/91 and subsequent Framework Law on Environmental Noise 447/95 set the maximum daytime and nighttime acceptability limits for noise pollution levels with reference to the physical and functional characteristics of the local area and how it is used.

The Italian Framework Law on Environmental Noise 447/95 established the competences of the government and the different local authorities. The municipalities have to:

- adopt the acoustic zoning;
- provide the coordination with the town planning system adopted, especially with plans regarding noise sources;
- adopt the noise abatement plan

DPCM 14/11/97 defines the threshold of the different limit values (Table 1):

- emission limit value: maximum noise value emitted by the source, measured in proximity to the noise source, but close to spaces occupied by the public;
- input limit value: maximum noise value introduced into enclosed or outdoor spaces by the whole of the noise sources, measured close to the receptor;
- quality value: noise value to achieve in the future, in order to obtain the aims expected by the law.

The limit values mentioned in Table 1. are referred to the ambient noise at the receiver and 1m outside the building facade.

The limit values are not referrers to the transport infrastructures: road, railway, airport, port, etc. The Decrees on transport infrastructures establish the “buffer zones”: areas, with a defined width, where are in force specific limit values, related exclusively for the noise emitted by the considered infrastructure, usually higher then limits expressed by the acoustic zoning. Out of the “buffer zones”, the noise emissions of the infrastructure contribute to the limit values of the considered area.

For example, the Presidential Decree No. 142 [4] set the maximal noise levels for new and existing road infrastructures (Table 2 and Table 3). Noise-relevant band breadth is the width of land measured in horizontal projection, for each side of the road, starting from the border road.

All the municipalities are obliged to define the acoustic zoning, which represents the most important act, considering the acoustic planning, able to manage the environmental noise.

The acoustic classification of the territory, or acoustic zoning, classifies the territory of the municipality in six areas, related to different city planning characterization, activities and conditions for the use of the territory.

The six homogeneous areas are characterized by different input noise limit values, in Leq (A), on two temporal periods, referred to day period (06-22) and night period (22-06). In

conformity with the norm UNI 9884, green color refers to the class I, yellow to the II, orange to the III, vermilion red to the IV, violet red to the V and blue to the VI [5].

The Framework Law prescribes, related to Acoustical territorial zoning, the prohibition of the direct contact of the areas characterized by a difference of the limit values higher than 5 dB(A) of Leq measured.

If the respect of this duty is not possible, especially in urban areas, an abatement plan will be expected.

Table 1. *Limit values defined by DPCM 14/11/97*

Territorial areas	Input limit value Leq dB(A)		Emission limit value Leq dB(A)		Quality limit value Leq dB(A)	
	day	night	day	night	day	night
Area I – Particularly protected areas: the areas belong to this zone are territories where the quiet represents a priority characteristics: hospitals, schools, areas dedicated to relax and recreation, public park, residential rural areas, more interesting urban planning areas, etc.	50	40	45	35	47	37
Area II – Areas mainly dedicated to a residential use: the areas belong to this zone are mainly characterized by local road traffic, low population density, low presence of commercial activities and absence of industrial and handcrafted activities.	55	45	50	40	52	42
Area III – Mixed areas: the areas belong to this zone are characterized by local and crossing road traffic, by media density of population, presence of commercial activities, offices, low density of handcraft activities and absence of industries; rural areas characterized by the presence of equipment.	60	50	55	45	57	47
Area IV – Intensive human activities areas: the areas belong to this zone are characterized by busy road traffic, high density of population, high presence of commercial activities and offices, presence of handcraft activities; areas close to main road traffic and railway infrastructure; ports, areas with a presence of factories.	65	55	60	50	62	52
Area V – Mainly industrial areas: the areas belong to this zone are characterized by the presence of factories and a low presence of residential buildings.	70	60	65	55	67	57
Area VI – Exclusively industrial areas: the areas belong to this zone are interested exclusively by industrial activities and there are not residential buildings.	70	70	65	65	70	70

Table 2. *Limit values for new road infrastructures*

Road types	Sub-types	Noise-relevant band breadth (m)	Schools*, hospital, rest/nursing homes Leq dB(A)		Other receptors Leq dB(A)	
			day	night	day	night
A - Motorway		250	50	40	65	55
B - Main out-of-town roads		250	50	40	65	55
C - Secondary out-of-town roads	Ca - Dual carriageway	250	50	40	65	55
	Cb - All secondary out-of-town roads	150	50	40	65	55
D - Urban fast roads / dual carriage ways		100	50	40	65	55
E - District urban		30	Defined by DPCM 14/11/97 and compliant with noise zoning of urban areas			
F - Local		30				

Table 3. *Limit values for existing road infrastructures*

Road types	Sub-types	Noise-relevant band breadth (m)	Schools*, hospital, rest/nursing homes Leq dB(A)		Other receptors Leq dB(A)	
			day	night	day	night
A - Motorway		100 (group A)	50	40	70	60
		150 (group B)			65	55
B - Main out-of-town roads		100 (group A)	50	40	70	60
		150 (group B)			65	55
C - Secondary out-of-town roads	Ca - Dual carriageway	100 (group A)	50	40	70	60
		150 (group B)			65	55
	Cb - All secondary out-of-town roads	100 (group A)	50	40	70	60
		150 (group B)			65	55
D - Urban fast roads / dual carriage ways	Da - Inter-district dual carriageway	100	50	40	70	60
	Db - All urban fast roads / dual carriage ways	100	50	40	65	55
E - District urban		30	Defined by DPCM 14/11/97 and compliant with noise zoning of urban areas			
F - Local		30				

* For schools is the only daytime limit

3.2 Serbian legislation

The Serbian Law on Environmental Noise [6] regulate: subjects of environmental noise protection; measures and conditions for environmental protection against noise; environmental noise measurements; access to the information on noise; surveillance and other issues relevant for environmental protection and human health.

The Law on Environmental Noise established the competences of the government and the different local authorities. The municipalities have to:

- determine measures and requirements for protection against noise, i.e. sound protection in plans, programmes, and projects, including those to which it gives approval in the strategic impact assessment procedure, environmental impact assessment, or IPPC permitting procedure;
- perform acoustic zoning in its territory, determine prohibits and restrictions in accordance with the Law;
- enact local environmental noise protection action plans, i.e. provide for conditions and take care of its implementation;
- provide financing for environmental noise monitoring in the territory of local self-government units;
- supervise and control implementation of environmental noise protection measures.

Degree on Methodology for Determination of Acoustic Areas [7] closely prescribes the methodology for determination of acoustic areas.

Determination of acoustic zones shall be done based on referent spatial planning maps showing the land use, settlement network and infrastructural systems, touristic areas, natural and immobile cultural resources, and based on the referent urban planning maps showing the prevailing land use, division as per zones and parts according to morphological, planning, historical-ambient, shaped and other characteristics.

Acoustic zones shall be determined according to the existing development status, land use, as well as according to planned land use and shall be defined through noise indicators limit values (day and night-time), expressed in decibels.

Acoustic zoning classifies the territory of the municipality in six areas, related to different city planning characterization, activities and conditions for the use of the territory. The zones are defined in [5] and shown in Table 4.

The six homogeneous areas are characterized by different noise limit values on three temporal periods, referred to day period (06-18), evening period (18-22) and night period (22-06).

Regulation on Noise Indicators, Limit Values, Assessment Methods for Indicators of Noise, Disturbance and Harmful Effects of Noise in the Environment [8] prescribe environmental noise indicators, limit values, assessment methods for indicators of noise, annoyance and harmful effects of noise to human health.

Limit values for noise indicators in settlements, according to residential zones, are given in Table 4. Limit values are equal for day and evening time. The limit values refer to overall noise from all sources in the considered area. Limit values provided for in Table 4 refer to common noise indicators and the rating noise level.

Table 4. *Limit values for oudoor noise indicators*

Zone	Land use	Noise level in dB (A)	
		Day and evening	Night
1.	For rest and recreation, hospitals and recovery facilities, cultural-historical locations, large parks	50	40
2.	Touristic areas, camps and school zones	50	45
3.	Residential areas	55	45
4.	Business-residential areas, commercial-residential areas and children's playgrounds	60	50
5.	City centre, trade, commercial, administrative zones with dwellings, areas along the motorways, main roads and city roads	65	55
6.	Industrial, storage and servicing areas and transport terminals without dwellings	At this area borders, noise must not exceed the limit value of the neighbouring area	

4. ACOUSTIC ZONING EXAMPLES

4.1 Acoustic zoning in Italy

According to what has been prescribed by the Italian legislation, the territory of many Italian cities (Rome, Palermo, Taranto, Naples, Bologna, Modema, Florenca, Chioggia (Venecia district), etc.) have been divided into six classes of use destination, associating to each of them limit values of emission, immission and quality. The examples of the acoustic zoning plan are given in Fig. 1 and 2 for Rome and Taranto territory.

The distributions of the noise zones within the municipal territory for some Italian cities are reported in Table 5 [9, 10]. The zone III covers the majority of the territory except for Naples.

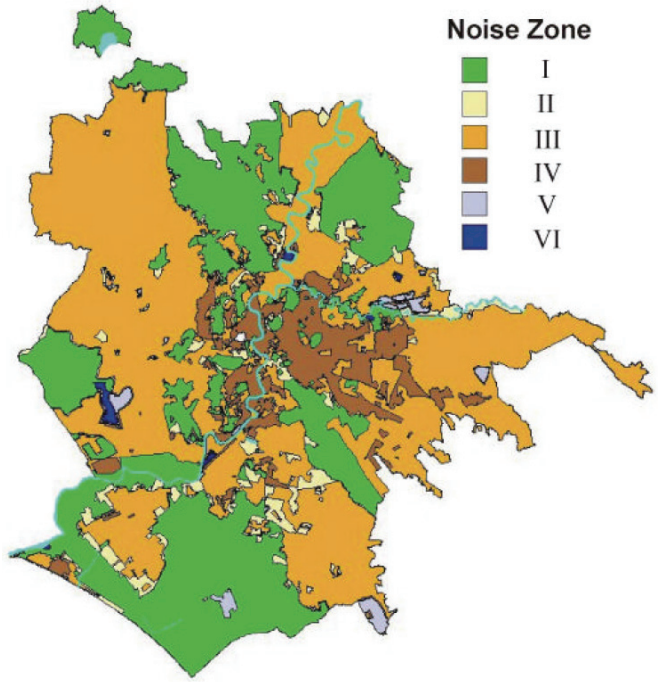


Fig. 1 *Noise zoning plan of Rome [9]*

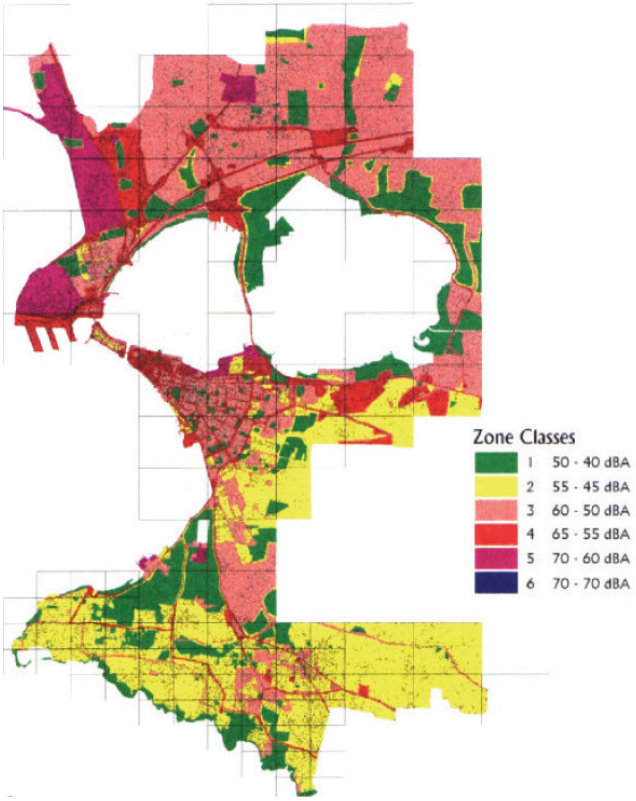


Fig. 2 *Noise zoning plan of Taranto [10]*

Table 5. *Distribution of the noise zones (percentage of the municipal territory) in Italian cities*

City	Rome	Taranto	Naples	Bologna	Modena
Inhabitants/ km^2	1912		8500	2638	960
Zone I	32.6	17.0	26.4	4.0	1.8
Zone II	5.0	31.0	19.4	23.0	3.6
Zone III	52.1	34.0	21.9	45.0	78.1
Zone IV	8.7	11.0	28.9	18.0	13.1
Zone V	1.1	7.0	2.6	9.0	3.4
Zone VI	0.3	0	0.8	0	0

4.2 Acoustic zoning in Serbia

The acoustic zoning of some Serbian cities (Šabac, Smederevo...) were carried out according to the Serbian regulation [6, 7, and 8].

The territory of Šabac has been divided into five zones by Degree of measures for noise protection [11]. No part of territory was defined by the acoustic zoning as a residential zone. The zone 1 (rest and recreation, hospitals and recovery facilities, cultural-historical locations, large parks) covers the majority of the territory (Fig. 3).

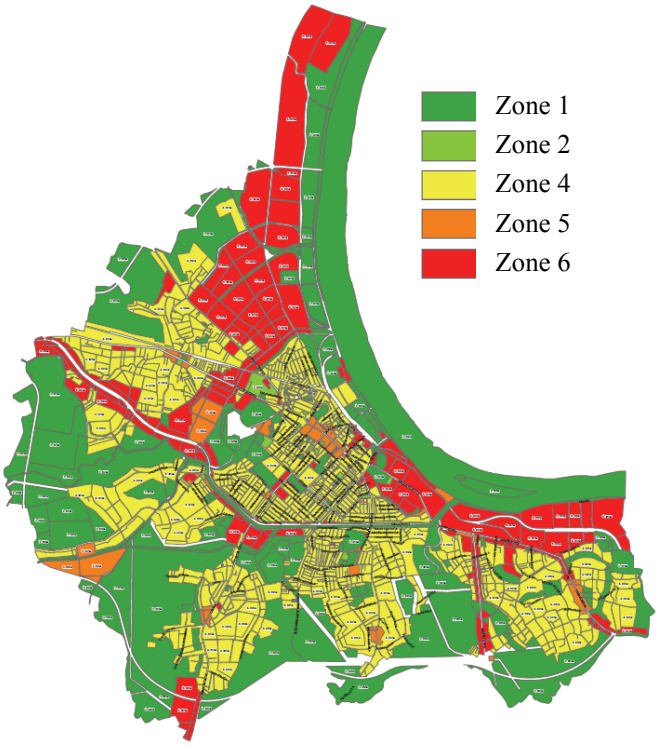


Fig. 3 *Noise zoning plan of Šabac [11]*

The acoustic zoning of city of Nis will be presented in detail. Draft of acoustic zoning plan (Fig. 4, 5) has been finished and final version will be created after revision of draft plan by the municipal authorities.

The acoustic zoning of city of Nis has been carried out taking into account the areas defined by Spatial Plan of the Administrative Area of the City of Nis in the period 2011-2021. and General Urbanistic Plan in the period 2010 - 2025, their densities of population, office buildings, shops, factories, and activities related to sport and recreation.

City of Nis is one of the oldest cities in the Balkans. It is the second largest city in Serbia. The administrative area of city of Nis extends for 596.71 square kilometers and covers five municipalities (Crveni krst, Pantelej, Medijana, Palilula, Niška banja). According to the preliminary results from the 2011 census, the whole municipal area of the city of Niš (including both, urban and rural parts of municipality) has a population of 257.867, while the population of urban Niš was 177.972, while its administrative area has a population of 257.867.

Nowadays, the city is connected by the highway E75 with Belgrade and Central Europe in north, and Skopje, Thessaloniki and Athens in the south. The road E80 connects Niš with Sofia, Istanbul towards the Middle East, and Pristina, Montenegro and the Adriatic Sea to the West. The road E771 connects the city with Zaječar, Kladovo and Drobeta-Turnu Severin in Romania. The city is also a major regional railway junction. The Niš Constantine the Great airport is the second most important airport in Serbia. The first airfield was built in 1910. The city public transportation consists nowadays by 14 bus city lines and 48 bus suburban lines. The city is crossed by main roads, city roads and collector roads with the total length of 275 kilometers. Road traffic noise measurements were also carried out in the period 1996 to the present day.

A digital drawing of the territory (in a .dwg file) was firstly examined especially:

- land use plan;
- residential areas plan;
- business areas plan;
- industrial areas plan;
- transport network plan.

The classification of the territory of the municipality in homogeneous areas characterized by the noise limit values is carried out by the identification of the six areas, through the main following parameters:

- density of population;
- presence and typology of road and railway traffics;
- presence and importance of commercial, handcraft and industrial activities
- presence of “sensitive receptors”: activities, and buildings where they are carried out, which have to be more protected (hospitals and recovery facilities, cultural-historical locations, schools)

The first step for the characterization of the six areas was the identifying of the areas more easily identifiable:

- the zone 1 and zone 2, (particularly protected area), characterized by higher protection and lower limit values (40-50 Leq dB(A)), and
- the zone VI (mainly industrial areas).

The following areas were classified by qualitative method as particularly protected areas (zone 1 and zone 2):

- hospital, home for the aged;
- schools (elementary and secondary schools, faculties and university);
- areas dedicated to relax and recreation;
- touristic areas;
- public park,
- more interesting archeological and cultural zones.

The following areas were classified by qualitative method as industrial areas (zone 6):

- business and industrial zones, production and infrastructural facilities;
- storage of industrial character without residential buildings.

Afterwards, the areas were classified into zone 3, 4 or 5 by quantative method according:

- density of population (number of inhabitants per square meters);
- presence of commercial activities and offices (area of the store / total area);
- presence of handcrafted activities (area of the stores / total area);
- typology of road traffic (number of vehicles per hour).

The road and rail networks and their buffer zones indicated in Table 6. are placed on the previous acoustic zones identified.

The width of buffer zones around road is not defined by the Serbian regulation. The values of the buffer zones given in the table 6 are determined by the authors of this paper based on the characteristics of the roads in the city of Nis.

The width of buffer zones is the width of land measured in horizontal projection starting from the border road.

Table 6. *The width of buffer zones around road*

Road types	*Width of buffer zone (m)*
Highway	25
Motorway	20
Regional road	15
Local road	10
City highway	10
Arterial road	15
Collector road	10
City rail	15

By the analysis of the draft of the noise zoning plan it can be concluded that the zones 3 (residential areas) and 5 (city centre, trade, commercial, administrative zones with dwellings, areas along the motorways, main roads and city roads) cover the majority of the administrative area of the city of Nis (Fig. 5). In contrast, the zone 4 (business-residential areas, commercial-residential areas and children's playgrounds) covers the majority of the Municipality of Medijana (the central municipality of the city of Nis).

CONCLUSION

The acoustic zoning, which is a method of delineating areas with particular requirements, is a logical step in planning to achieve the necessary reconciliation between the desired comfort of living in the cities and the noise source.

For the classification of areas into acoustic zones can be used quantitative criteria and/or quality. In general, the attribution of extreme classes (particularly protected areas and industrial areas) is directly, using a qualitative method, the intermediate classes instead most frequently assigned through quantitative methods, based on analysis of parameters (population density, density of commercial establishments, production activities, offices, traffic...). With well-integrated geographical information and land use, the quantitative method can allow working more quickly for the allocation of zones, making uniform approach in different situations, constraining the choices assessments more objective.

To achieve the objective of an "acoustical planning" of the territory, able to control noise emissions, cooperating with the existing "planning system", it is also important to avoid the excessive subdivision of the zoning, the breaking up of the territory into small areas.

A comparison of legislation and experiences in acoustic zoning in Italy and Serbia shows that there is the similar approach in the acoustic zoning but that there are differences especially in the determination of limit values different for different sources of noise.

ACKNOWLEDGEMENT

This research is part of the project "Development of methodology and means for noise protection from urban areas" (No. TR-037020) and "Improvement of the monitoring system and the assessment of a long-term population exposure to pollutant substances in the environment using neural networks" (No. III-43014. The authors gratefully acknowledge the financial support of the Serbian Ministry for Education, Science and Technological Development for this work.

REFERENCES

[1] Degree of the President of Council of Ministers DPCM 1/3/91, "Maximum exposure limits to noise in enclosed and open spaces" http://www.regione.piemonte.it/ambiente/rumore/dwd/norm_strad/DPCM_1marzo_1991.pdf, in Italian.

[2] Framework Law on noise pollution 447/95, http://www.arpa.emr.it/cms3/documenti/rumore/normativa/L_447_26ott1995.pdf, in Italian.

[3] Degree of the President of Council of Ministers DPCM 14/11/97, "Definition of the limit values of the noise pollution", http://www.regione.piemonte.it/ambiente/rumore/dwd/norm_strad/DPCM14NOV97.pdf , in Italian.

[4] Degree of the President of Republic 142/2004, "Provision for containment and prevention of noise pollution caused by traffic, in accordance with Article 11 of Law October 26, 1995, n. 447.", http://www.autostrade.it/en/risanamento-acustico/pdf/D-P-R-30-marzo-2004-n-142.pdf, in Italian

[5] S. Barbaro, R. Caracausi, "Noise in hospital areas - measure and evaluation", *In Proc. of 14th International Congress on Sound and Vibration*, 2007, Australia

[6] Law on Environmental Noise, "Official Gazette of RS", no. 36/2009 and 88/2010

[7] Degree on Methodology for Determination of Acoustic Areas, "Official Gazette of RS", no. 72/2010

[8] Regulation on Noise Indicators, Limit Values, Assessment Methods for Indicators of Noise, Disturbance and Harmful Effects of Noise in the Environment, "Official Gazette of RS", no. 75/2010

[9] G. Brambilla, "Noise and Soundscape in Rome", *in Proc. of 147th Meeting of the Acoustical Society of America*, 2004, New York

[10] L. Cosimo, G. Umberto, "Acoustic zoning and noise map of the territory of Taranto (Italy), Tecni Acustica, 2000, Madrid

[11] *Degree of measures for noise protection, "Official Gazette of city of Šabac", no. 28/2011*

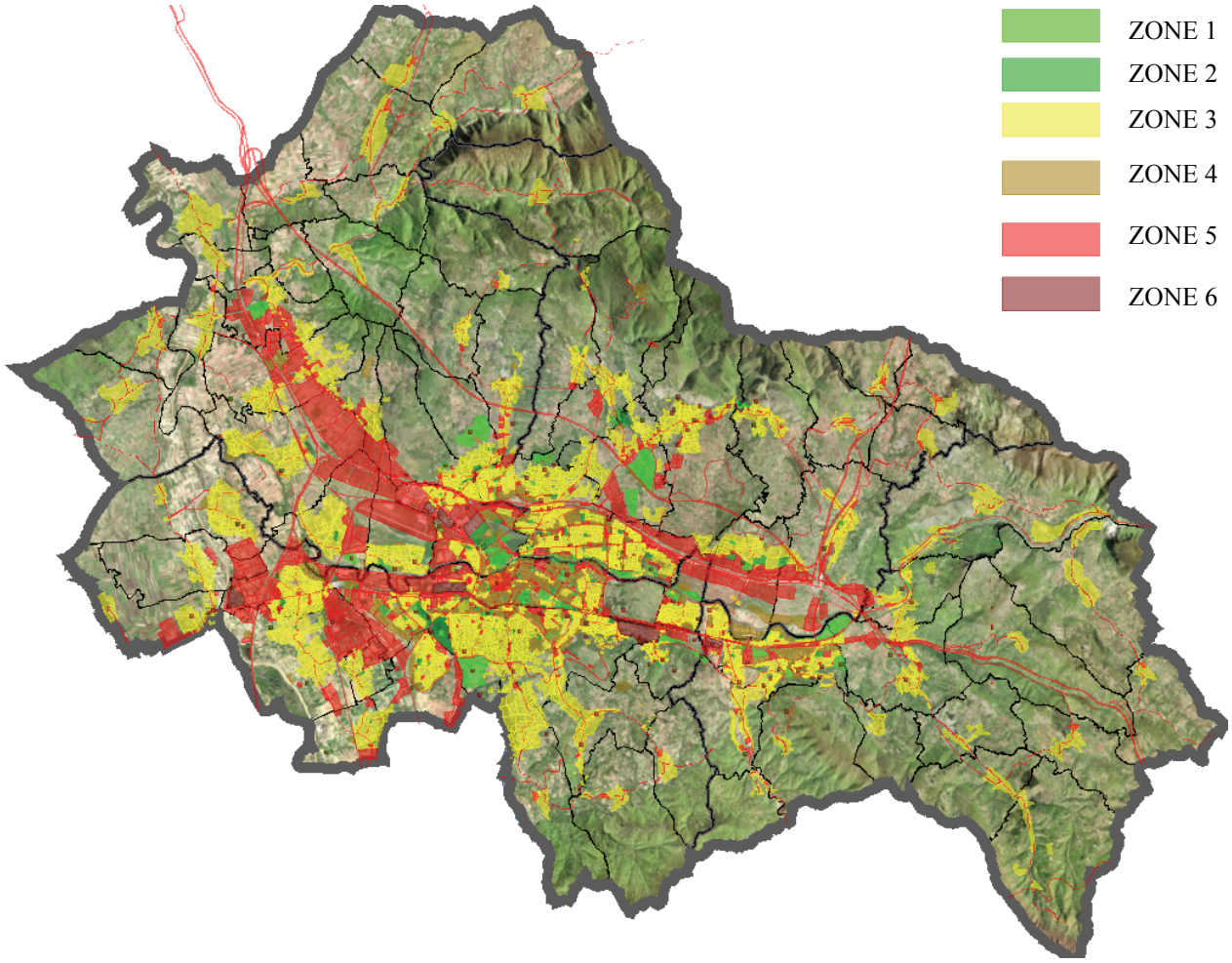


Fig. 4 *Draft of noise zoning plan of administrative area of the city of Nis*



***Fig. 5** Draft of noise zoning plan of the Municipality of Medijana*

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

ENVIRONMENTAL NOISE MAPPING, ACTION PLANNING AND NOISE MONITORING IN BULGARIA

Boris Mihaylov[1], Milcho Georgiev[2]

[1] SPECTRI LTD. (www.spectri.bg), Bulgaria, spectri@spectri.net
[2] Technical University of Sofia, SPECTRI LTD., georgievmt@spectri.bg

Abstract - *The purpose of strategic noise mapping is defining the level and characteristics of noise pollution in the environment of large cities (agglomerations) – using standardised unified methods of measurement, monitoring, calculation, assessment and noise prediction. The final aim is to determine exact dedicated action plans - based on the strategic noise management (restriction and reduction of the environmental noise impact), and applying set of measures and acoustical planning in short, middle and long terms. The action plans (measures) shall be focused to specific areas where an over limit noise exposure is prevailing (when human health is under risk), and at the same time maintaining the noise levels for areas where they are within the limits. The overall aim is to provide healthy life conditions and justified enviromental noise policy – via implementing an integrated approach. The paper provides an expert overview of relised noise mapping and action planning projects in Bulgaria – from the Bulgarian leading company in the domain of acoustics and vibration engineering, Spectri Ltd.*

Presented – methodology, empiric approach, and highlights from realized projects.

Key Words: - Strategic noise map(s), action plan(s), environmental noise.

1. INTRODUCTION

(A) Producing strategic noise maps for aglomerations we are facing the task of generating the following individual noise maps:

- For noise source, automobile traffic;
- For noise source, rail traffic;
- For noise source, air traffic;
- For noise source, sea/river traffic;
- For noise source, industrial activity;
- Other specific noise sources;

The strategic noise maps contain text, and graphical information for:

- previous, actual, and future noise impact situation defined via the noise indexes;
- overlimit values information;
- the number of dwellings, children and hospital buildings, schools and scientifical organizations - exposed to significant noise impact;
- number of people, noise exposed;

The srategic noise maps for the aglomerations include:

- overal (combined) strategic noise map – representing the noise levels as a result of all sources' influence to the respective territory (at height 4.00 ± 0,2 m (3.8 - 4.2 m);
- individual strategic noise maps for automobile traffic, rail traffic, air traffic, sea/river traffic, industrial activity, other specific noise sources.

(B) In respect with the national and European legislation, the action lans shall include:

- Aglomeration's description;
- Responsible authorities for implementation of different defined measures;
- Estimation and analysis of the noise impact in the last 5 years;
- Analysis of the main factors lead to overlimit noise influence;
- Resume of the official strategic noise map for the aglomeration;
- Applied measures dedicated to overall noise reduction, and measures under preparation;
- Estimation of the number of people less affected of overlimit noise influence – as a result of the foreseen noise reduction measures effect;
- Definition of the main problems with priority focus;
- Formulating the neccessary actions leading to improving of the total acoustics enviroment in the agglomeration – in short, middle, and longterm aspects. Listing the responsible authorites, institutions and persons, terms for implementation, financial sources and budget estimation;
- Analysis of the expected overal noise impact improvement – as result of the suggested measures and actions (affected population groups, and expected noise expositions reduction to certain number of peopl). Evaluation of every prescribed measure and action;
- Putting in priority order of the different measures – using the criteria of population exposure noise impact reduction;
- Protocols of conducted public consultations. Summary of performed official public discussions;

2. METHODOLOGY, MAIN PROJECT STAGES

2. 1. Calculation methods

The following calculation methods have been used (for the strategic noise maps calculations – as per Apendix II - 2.2. of EU Directive 2002/49/EC, recommended methods):

- FOR NOISE SOURCE "AUTOMOBILE TRAFFIC": The French national method – "NMPB-Routes-96", standard "XPS 31-133";
- FOR NOISE SOURCE "RAIL TRAFFIC": Holland national method – "RMR";
- FOR NOISE SOURCE "AIR TRAFFIC": – ECAC, CEAC Doc 29 – "Report on Standard Method of Computing Noise Contours around Civil airports ", 1997.
- FOR NOISE SOURCE "INDUSTRIAL ACTIVITY": ISO 9613-2 (+ ISO 8297Q 1994 + EN ISO 3744Q 1995 + EN ISO 3746Q1995).

2. 2. National and European applied legislation

- Bulgarian Enviroemntal Noise Protection Law (2005);
- European Noise Directive (END) 2002/49/EC;
- EC Good practice guide for strategic noise mapping (EC exper noise group paper – WG-AEN, 2006);
- Bulgarian Ordinance re. Stratecis noise mapping and action plans (2006);
- Bulgarian Ordinance re. The national noise monitoring system, and industrial noise sources public information (2011);
- Bulgarian Ordinance re. agglomerations, main roads, main airports, and main rail tracks registers (2006);
- Bulgarian Ordinance for noise indexes, and limit values (2006).

2. 3. Validation measurements, methodology

Performed maps verification, using Brüel & Kjær measurement instrumentation – terminals 3639, sound level meters 2250, different software packages.

- Applied standards: ISO 1996-1/2005, ISO 1996-2/1987;
- Performed SPECTRI measurements on every noise point in 2 stages (winter/summer).

Used as well external noise measurement data – from the National Noise Monitoring system, and as well from available historical results, generated from local permanent noise monitoring systems.

Conducted verification – between measured value and calculated with software LimA model results. If not accepted result (3 dB deviation) – started respective reverse engineering procedure.

2. 4. Main project stages

- Defining and obtaining various needed input data for the different noise sources, and overall enviromental conditions and plicy;
- GIS data delivery;
- Initial noise model creation;
- Field measurements;
- Calibration, reverse engineering;
- Public discussions;
- Paper creation, and submission for evaluation (Ministry of Health, Ministry of Environmental);
- Final corrections;

See fig. 1 re. In deep defined project's steps.

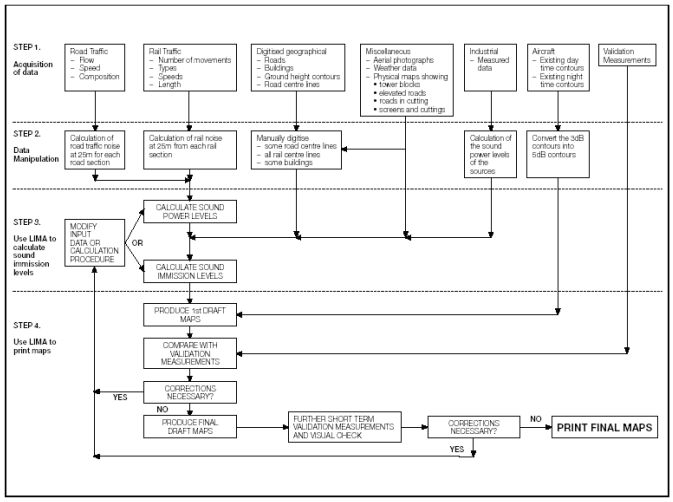


Fig. 1 *Main steps re. Strategic noise mapping*

2. 5. Action planning, defined measures

Performing of expert evaluation of in forced overal enviromental policy. Estimation of noise mapping results, prioritisng of main affected snesible overlimit exposed areas and population. Consideration of possibly available financial sources.

The measures proposed are (a) organizatorical, (b) investment active acoustical measures, (c) non investment normative issues.

The active measures for noise reduction can be the popular acoustics noise barriers implementation – calculated and considered as per the well known principle shown in fig. 2.

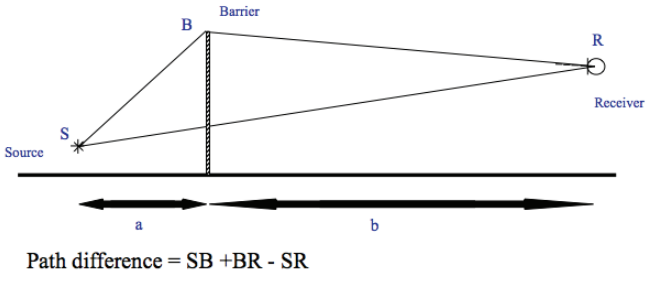


Fig. 2 *Barrier attenuation*

3. CONCLUSIONS

The result and main conclusion from the projects SPECTRI Ltd. has been involved into are (main projects – strategic noise mapping and action plans for Sofia, Plovdiv, Burgas, Varna, Ruousse, Pleven, Bulgarian Road's Agency):

- Main noise impact is caused from automobile trafic noise;
- Local influence of rail traffic source;
- Very low inpact of industrial noise sources;
- The air traffic impact, esp. in biggest cities with airports located near urbanised territories is anoying certain group of inhabitants (Sofia, Varna, Burgas). The landing, and departure procedures and policies shall be totally reconsidered;
- Influence into legislation level, and implementation of good practices shall be implemented (example – now when building up new roads in Bulgaria, the noise factor is considered, and when needed noise barriers are installed).

REFERENCES

[1] Bulgarian Enviroemntal Noise Protection Law (2005);

[2] European Noise Directive (END) 2002/49/EC;

[3] EC Good practice guide for strategic noise mapping (EC exper noise group paper – WG-AEN, 2006);

[4] SPECTRI Ltd. case stories.



Environmental Noise Monitoring

Noise monitoring is being adopted throughout the world as a means to reduce noise impact from the everyday activities that go on around us. Monitoring produce trend information for planning and compliance purposes as well as process data to highlight noise disturbances for investigation — working with you to reduce noise!





Sound and Vibration - Brüel & Kjær!

Brüel & Kjær is a global company providing local sales, service, and support in more than 55 countries.

Contact your local sales representative:

RMS d.o.o.
Partizanske avijacije 12/3,
11070 Novi Beograd, Srbija,
Tel.: +381(0)11 2280 951
Fax: +381(0)11 2280 751
http://www.rms.rs

Brüel & Kjær Sound & Vibration Measurement A/S / Export Sales
Skodsborgvej 307, DK-2850 Nærum, Denmark
Tel.: +45 7741 2000 — Fax: +45 7741 2015
E-mail: export@bksv.com — Website: http://www.bksv.com

Brüel & Kjær

University of Nis
Faculty of Occupational Safety

„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

TRAFFIC NOISE ACTION PLANNING IN AGGLOMERATIONS REDUCTION POTENTIALS BASED ON GERMAN GOOD PRACTICE EXAMPLE

Jovana Đilas[1]

[1] Deutsche Bundesstiftung Umwelt scholarship holder, Hartwig Hesse Straße 18, Hamburg, Germany, djilasj@gmail.com

Abstract - *This paper presents means for sustainable traffic noise action planning in agglomerations which are used in order to achieve required noise protection, considering that preparation and implementation of Action plans is one of the key elements of The Environmental Noise Directive (2002/49/EC). Within this paper are shown different measures for noise mitigation and their influence and efficiency in terms of good noise protection, based on example of German practice. In order to obtain relevant data, necessary for the research, software package for noise mapping IMMI was used.*

1. INTRODUCTION

Noise is one of the major environmental hazards of modern world originating from a wide variety of sources. Transport noise is an increasingly prominent feature of the urban environment, making the noise pollution an important environmental and public health issue.

In comparison to other pollutants, the control of environmental noise has been hampered by insufficient knowledge of its effects on humans and of dose-response relationships as well as a lack of defined criteria. While it has been suggested that noise pollution is primarily a "luxury" problem for developed countries, one cannot ignore that the exposure is often higher in developing countries, due to bad planning and poor construction of buildings. The effects of the noise are just as widespread and the long term consequences for health are the same. In this perspective, practical action to limit and control the exposure to environmental noise are essential [1]. Recent studies indicate that environmental noise is an important environmental risks threatening public health and that noise exposure in Europe presents an increasing trend compared to other stressors. Taking all exposure to transportation noise together about half of the European Union citizens are estimated to live in zones which do not ensure acoustical comfort to residents. The assessment relating to the first round of noise mapping suggests that around 40 million people across the EU are exposed to noise above 50 dB from roads within agglomerations during the night [2].

2. NOISE CONTROL APPROACH

Noise action planning is a multidisciplinary task which implies broad interaction of different planning disciplines.

Powerful planning tools are nose maps which are used to set realistic targets for noise reduction and for a more effective use of planning controls to reduce noise from new noise sources, to protect new noise sensitive developments from existing noise sources and to identify, protect and create quiet areas. The maps can also be used as a tool to provide information to the public, politicians and noise professionals on noise problems in a city and the location of these problems.

Action plans must at least include the following indications and elements:

- A description of the agglomeration, the major roads, the major railways or major airports and other noise sources taken into account;
- The authority responsible, the legal context; any limit values in place; a summary of the results of the noise maps; an evaluation of the estimated number of people exposed to noise;
- An identification of problems and situations that need to be improved;
- A record of the public consultations and any noise reduction measures already in force and any projects in preparation;
- Actions which the competent authorities intend to take during the next five years. Including any measures to preserve quiet areas; the long-term strategy;
- Financial information (if available): budgets, cost-effectiveness assessment, cost-benefit assessment; cost-benefit analysis, provisions envisaged for evaluating the implementation and the results of the action plan.

An integrated noise policy should include several control procedures: measures to limit the noise at the source, noise control within the sound transmission path, measures at receiver itself. Ideally, countries should give priority to precautionary measures that prevent noise, but they should also put in to practice measures to mitigate existing noise problems [3].

2.1 Measures to limit the noise at the source

- Traffic management;
- Low-noise road surfaces;
- Technical measures at noise source;
- Driver behavior and the introduction of certain 'ban'.

2.1.1 Traffic management

The effect-based approach for promotion of local public transport embraces conceptual approaches for expansion of local public transport, Park&Ride and Bike&Ride facilities as well as parking management. All these four approaches have the objective of shifting the choice of transport mode from the car to local public transport, reducing traffic volume as well as a changing traffic composition.

Promotion of bicycle traffic: besides the expansion of local public transport, the promotion of bicycle traffic is an important component of the promotion of environmentally-friendly modes of transport. According to the report "Mobilität in Deutschland" , 60 % of all journeys undertaken in Germany are shorter than 5 kilometers and can therefore be made by bicycle. As result, a shift potential of about 18 % can be assumed in respect of this distance range.

Spatial shifting of traffic: Conceptual approaches to the spatial shifting of traffic apply to a very great extent to HDV traffic, which gives rise to markedly higher noise exposure per vehicle than car traffic, and is therefore of particular significance for impact assessment [4].

Speed reductions: As reductions in driving speed have substantial effects on traffic noise emissions, especially at urban speeds, lowering speed limits appears to be a feasible approach to reducing noise emissions from road traffic. Possible are speed reductions on certain roads or for complete areas. According to a German study [5], the introduction of 30 km/h zones into residential streets allows a reduction up to 3 dB(A). In Baden-Wurttemberg [6], the introduction of these zones on the whole of a city allows reductions up to 2 dB(A). Another German study [7] concluded that the change from 50 to 30 km/h lowers 5 dB(A) the maximum level and 3 dB(A) the equivalent level.

Road narrowing installation: conditions to optimize their effects. Based on the experiments in Geneva [4] a road narrowing can lead to decrease in noise up to 2 dB(A). The setting of suitably dimensioned works (central blocks, traffic islands, parking bays, cycle tracks, etc.), reservation of a way for public transport for each direction of circulation, the reduction of the number of ways for individual traffic, the creation of parking bays and the increased distance from the center of traffic to the facades, allowed a reduction of 2 dB(A).

2.1.2 Low-noise road surfaces

Low-noise road surfaces today are either thin layer surfaces or porous asphalts with one or two layers. Thin layer surfaces either can be open graded asphalt concrete, stone mastic asphalt or a combination pavement. The noise reduction potential is based upon a low aggregate size of the mixture (e.g. a maximum aggregate size of 6mm on urban roads and 8mm on highways). Porous asphalt reduces the noise generated by air forced out between the rubber blocks of the tire and the road surface (air pumping effect) and reduces propagation of noise from the engine and transmission system of the vehicle (sound is not reflected but absorbed by the porous layer). Porous asphalt has an open structure with about20-25% air void inbuilt. As a result, it absorbs noise and drains water. Single layer porous pavements have an average noise reduction of 3-4 dB on highways (in relation to dense asphalt concrete). Two-layer porous pavements have a noise reduction potential of up to 8dB [3].

2.1.3 Technical measures at noise source

In the context of road noise management the focus is put on the vehicles themselves, just like in the case of other noise sources. This is especially important for trucks as about 25 trucks per hour cause as much noise in road traffic as 400 cars (at 50 mph (80 km/h) and on the same road surface. Possible noise reduction measures are a sound-insulated enclosure of the engine, technical measures at the trailers (low-noise trucks) and the reduction of the rolling noises through quieter tires.

2.1.4 Driver behavior and the introduction of certain 'ban'

Driving styles have a high impact on the noise that is generated. Using low engine speeds and avoiding unnecessary high acceleration and vehicle speed values achieve a significant reduction of the propulsion noise of a vehicle. Less aggressive or passive driving styles are believed to reduce the noise on average by approximately 5 dB for cars and commercial vehicles and 7 dB for motorcycles.

2.2 Noise control within the sound transmission path

Noise barriers or screens are an effective, but very costly measure to reduce noise propagation alongside roads or railway lines. The main requirement is that the barrier should be sufficiently high and long enough. For the construction of barriers, a range of materials with different characteristics regarding absorption and reflection of sound is used (earth mounds, wood, steel, aluminum, concrete, masonry bloc, acrylic sheeting and rubber mats). In theory, noise screens could reduce noise levels by up to 15 dB(A). However, in practice, when the buildings are relatively close to the road (and the screen), the reduction is between 5 and 10 dB(A).Examples of Noise Barriers.

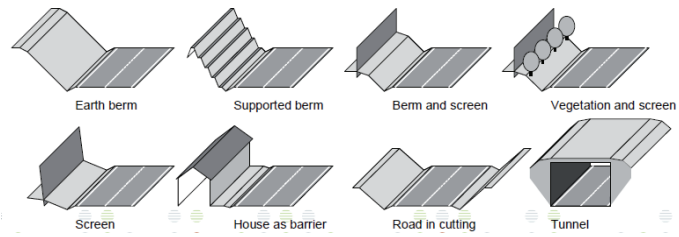


Fig 1 *Examples of Noise Barriers* [3]

2.3 Measures to limit the noise at the receiver

2.3.1 Land use planning

Avoiding and mitigating noise should be an integral part of land use planning and building design. The noise reduction potential is much higher when taken into consideration from

the very beginning of a new or re-development. Typical tools for land use planning are land use plans or zoning plans that cover the entire territory of the city. These plans can be used for noise abatement planning by: indicating (relatively) quiet spaces that are to be protected against new noise imissions; allocating land use in such a way that the distance between future noise emissions and noise-sensitive areas is big enough; avoiding the generation of additional traffic by sensible allocation of land use categories. Planning tools that cover only parts of a city such as development plans or plans for urban renewal / redevelopment also offer the opportunity to stipulate concrete measures to avoid or abate noise. The following measures can be used: noise-compatible buildings as noise barriers, building structure, allocation of buildings in combination with noise barriers, distance from source, the concentration of transport routes (a doubling of the traffic volume leads to a noise level increase of about 3 dB) and use of the topographic elements which are favorable in acoustic terms.

2.3.2 *Building design and sound insulation of objects*

In relation to the single building, there are more aspects to be considered for reducing the inside noise level. They concern the room plan, the shape and orientation of buildings, as well as sound insulation of walls and windows. In Figure 2. are presented examples of noise compatible arrangement of rooms inside of buildings and good building orientation to the road.

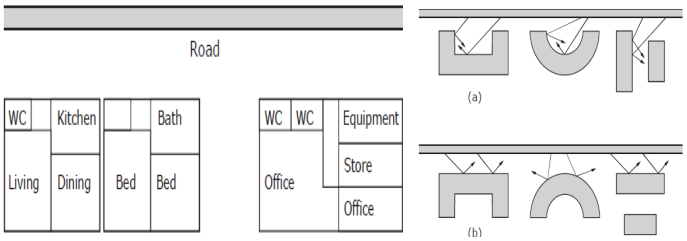


Fig. 2 *Noise compatible arrangement of rooms; Noise reflection at buildings to be avoided b) preferred* [3]

Sound insulation of dwellings, i.e. of the windows and outer walls of a building, is the last, but necessary option if other measures to reduce noise at the source or to abate its propagation fail to be sufficient. Building insulation today is widely considered as necessary when outdoor sound levels exceed 55 dB during the day and 45 dB LAeq at night. The main solution is sound insulated windows. They, however, reduce noise only sufficiently when closed. To solve this problem, other solutions have been developed, such as double pane windows with a special ventilation system or additional glass facades with separate ventilation that allows for opening the windows behind the facade. One of the examples of very efficient windows in terms of sound insulation are Hafen City-Fenster, which are used in Hafen City Hamburg. These are single or double layer windows with acoustic absorbers which provide required indoors noise protection of 30 dB allowing in same time fresh air flow.

In following chapter bigger attention will be devoted to the case studie of one Germany city with good implementation practice of different noise mitigation measures in order to resolve existing problem [3].

3. CASE STUDIE

Example is based on emerging middle-sized city in the metropolitan region of Hamburg. Just fewer than 49,000 inhabitants spread over 4 city districts, and about 21.5 km^2 urban areas. The existing urban area is about 13 km^2. The city it is very densely populated and recorded a high proportion of dwellings.

The main goal of conducted Noise control study was to determine the impact of traffic noise on the existing housing in Friedensallee in order to establish new City development plan i.e. to examine is it possible to build dwellings, which are closer to the road center line than existing buildings.

Study has shown that along the Friedensallee noise levels above 70 dB (A) during the day (Figure 3.) and 60 dB (A) at night(Figure 4.) have been reached or exceeded.



Fig. 3 *Existing noise levels during Day 06-22 pm* [8]

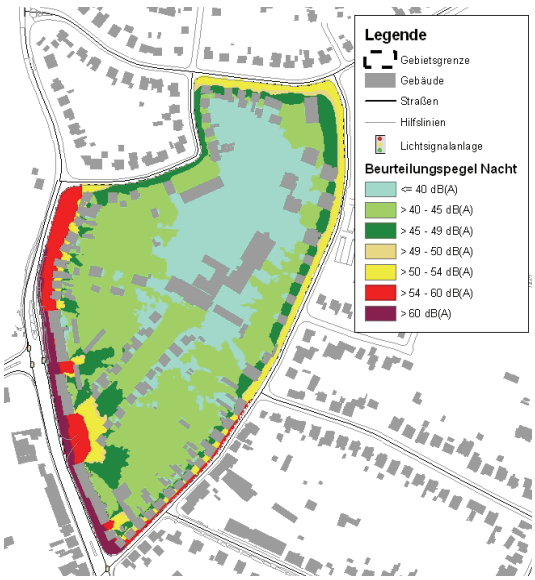


Fig. 4 *Existing noise levels during Night 22-06 am* [8]

The main objective is to examine possibility of lowering noise level in order to obtain $L_{day} \leq 70$ dB and $L_{night} \leq 60$ dB. Following a proposal from the city traffic planning office following measures for noise reduction have been introduced:

- Lane reduction of the Friedensallee between Amandastraße and Kleine Gärtnerstraße
- Speed reduction
- Low noise road surface

3.1 Lane reduction

Following a proposal from the city engineering office reduction Friedensallee to one lane in a northen direction between Amandastraße and Kleine Gärtnerstraße was examined. Moreover, noise action plan of the city also suggests the use of roadway cross-section reduction as a possible noise mitigation measure. Results obtained using software for noise mapping IMMI have shown minora reduction of noise level in the affected facades.

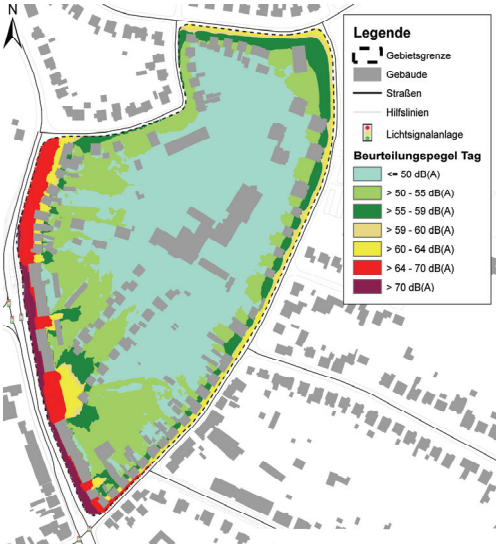


Fig. 5 *Noise level after lane reduction* [8]

3.2 Speed reduction

Another measure which has been investigated is a speed reduction from 50 km/h to 30 km/h in Friedensallee Reduction level is just under 3 dB(A). However actual level of reduction is lower near the crossing areas, because of the influences other roads (Figure 5.)



Fig. 6 *Noise level afte speed reduction* [8]

3.3 Low noise road surface

A great potential for nose reduction have low noise road surfaces. For this reason, it is examined use of an appropriate road surface from the intersection region Friedensallee / Amandastraße to the intersection Friedensallee / Kleine Gärtnerstraße.

For the investigation has been used DSH-V „Dünnen Asphaltdeckschichten in Heißbauweise auf Versiegelung“.

DSH-V has a special surface texture which prevents tire vibrations and good ability to provide sufficient near-surface cavities effectively eliminating so-called Air-pumping effect. The combination of these two features is key element of its acoustic efficiency. The noise reduction potential is from -3 to -5 dB (A). In this case achieved noise reduction is 5 dB (A).



Fig. 7 *Low noise road surface efficiency in nose reduction* [8]



Fig. 8 *Low noise road surface+lane reduction efficiency* [8]

It can be seen that with implementation of a lane reduction no significant noise reduction is achieved. Furthermore, a speed

limit of 30 km/h does not provide complete protection and limit values of $L_{day} \leq 70$ dB and $L_{night} \leq 60$ dB are not achieved in all reciver points. On the other hand, with combination of a speed limit of 30 km/h with the lane reduction significant improvements over the existing situation is noted. However, in the southern region of intersection several imission points exseed rating levels of 70 dB (A) for day. Best results are achieved with combination of a low-noise asphalt (DSH-V) and lane reduction. For all receiver points values below reading level have been achieved
(Fig. 8).

Furthermore, even with implementation of appropriate mitigation measures in the future is not going to be possible to build dwellings, which are closer to the road center line than the existing buildings. Moreover, in construction of new buildings noise compatible allocation of rooms should be taken in count. A quiet facade of building should be used for sleeping and living rooms. The required sound insulation of the living and sleeping rooms in the affected buildings should be ensured by passive noise protection measures in accordance with DIN 4109 and possibly also soundproof ventilation equipment for sleeping rooms [8].

4. CONCLUSION

Based on my research I can conclude that by the virtue of cutting edge programs and up to date solutions in field of noise management Germany is among the leading countries.

Research in this field led me to the conclusion that process of noise management and mitigation implies the use of standard tools which have been scope of this work. However, effective noise abatement planning involves need for consideration of locally specific issues and further adaptation of standard tools in order to bring the best solutions.

.

REFERENCES

[1] World Health Organization, Cluster of Sustainable Development and Healthy Environment (SDE), Department of the Protection of the Human Environment (PHE), Occupational and Environmental Health (OEH) "*Guidelines for Community Noise*", Geneva, 1999

[2] REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL *On the implementation of he Environmental Noise Directive in accordance with Article 11 of Directive 2002/49/EC,* Brussels, 2011

[3] www.silence-ip.org/site/fileadmin/SP_J/E-learning/Planners/SILENCE_Handbook_Local_noise_action_plans.pdf

[4] Lärmkontor GmbH On behalf of the Federal Environment Agency (Germany)*:* "*Noise acti on planning in agglomerations Reduction potentials based on the example of Hamburg*", Hamburg, 2011.

[5] Umweltbericht des Landkreises Starnberg Landratamt Starnberg*,* Starnberg, 2002.

[6] Bayer, O. et al., *Lärmbekämpfung – Ruheschutz Landesanstalt für Umweltschutz Baden-Württemberg (D),* Karlsruhe, 1995.

[7] Döldissen, A. et al*., Umweltauswirkung von Tempolimits Umweltbundesamt, Report 1,* Berlin, 1992.

[8] Lärmkontor GmbH, *Schalltechnische Untersuchung zu Maßnahmen an der Freidensalle der Stadt Elmshorn*, Hamburg, 2012

[9] B.K. Bose, "Sliding mode control of induction motor", in *Proc. IEEE Ind. Appl. Soc. Annu*. Meeting, 1995, pp. 479-48

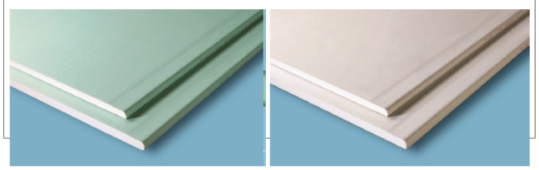
KNAUF

zvučna zaštita



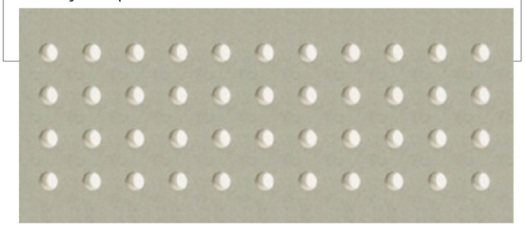
Masivna gipsana ploča

Robusna gipsana ploča za masivan karakter sistema suve gradnje
Masa 18,1 kg/m2 za debljinu ploče d=20 mm
Masa 21 kg/m2 za debljinu ploče d=25 mm



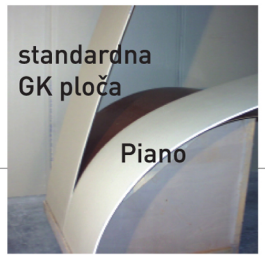
Cleaneo akustik

Perforirane (kružna i kvadratna perforacija) ili šlicovane gipsane ploče sa efektom pročišćavanja vazduha kroz aditiv od dehidriranog zeolita i kaširane akustičnim filcom
Debljina ploče d= 12,5 mm



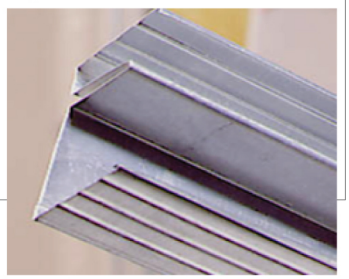
Piano

Gipka gipsana zvučno zaštitna ploča sa optimalnim odnosom osobina zvučne izolacije i mase 10 kg/m2 za debljinu ploče d=12,5 mm



MW profil

Knauf zidni profil za poboljšanu zvučnu izolaciju u „feder-masa" sistemu



Diamant

Tvrda gipsana ploča
povećane mase = 13,5 kg/m2
za debljinu ploče d=12,5 mm



Silentboard

Gipsana ploča za vrhunsku zvučnu izolaciju Ekstremne mase = 17,5 kg/m2
za debljinu ploče d= 12,5 mm



University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

NOISE MONITORING IN ZONE CONSTRUCTION OF A NEW SAVA BRIDGE IN BELGRADE - „BRIDGE ON ADA“

Predrag Petrović [1], Rade Mirović[2], Martin Jakscn[3], dr Manferd T. Kalivoda[3]

[1]Institute “Kirilo Savić“, Vojvode Stepe 51, Belgrade, Serbia, mpm@eunet.rs
[2]Porr, Milutina Milankovića 11a, Belgrade, Serbia
[3]psiA-Consult, Umweltforschung und Engineering Gmbh, Lastenstrase 38, A-1230 Wien

Abstract- *When building a very important buildings, must meet many requirements prescribed standards, including environmental requirements, in order to avoid harmful for health conditions of workers and surrounding population. In the zone of construction of the new Sava Bridge - "Bridge on Ada" in Belgrade had to be controlled by requirements on permissible levels of noise and vibration due to the presence in the work of a large number of machines and devices with their work causing increased noise and vibration.*
In this context, based on the scope of the project along the axis of the bridge are determined by the measuring points-axis zones whose noise level is measured and the results are shown in the audio folder.
Upon completion of the bridge over it will be done or tramway passenger traffic, with possession of bicycle and pedestrian paths, which will initiate increased levels of noise and vibration in the bridge area and access roads.
This paper presents selected excerpts from the report "psiA Consult" ,(M.Jaksch, M.T.Kalivoda), determining the noise monitoring in the area of bridge construction during 24 hours, for some months and years.

1. INTRODUCTION

Noise is defined as unwanted sound, which appears in the environment through means of: shouts, noise, magnifiers, speech, of machines of different plants, motor vehicles and the like, and that interferes with people in their work or vacation. During construction of the new Sava Bridge in Belgrade provided a continuous monitoring of noise and vibration along the entire site, from the street to „Paštrovićeva” , to „Omladinskih brigade”, in compliance with Directive 2002/49/EC of the European Union, and the ISO 1996-1, 2 and 3 (Measured: the equivalent, and pulse frequency noise), and in order to fully protect the living and working environment of workers and residents in the vicinity or in transit. In this area, during construction, the first stage required a large volume of earth and construction work in the immediate vicinity of residential areas, recreational and sports facilities, cultural and historical attractions, natural resources, existing and new roads(the access loop and the relocation of tram rails bridge) and other necessary procedures.
During construction, account is taken that the distance to the main half-ring of housing and natural resources, is the limits, as well as control of emissions, in the worst case is the previous level.

2. BRIDGE PROJECT DESIGN AND SIDE ROADS

During the project design of the new Sava bridge, which got its name - "Bridge of Ada", and its realization, we are sure to provide environmentally friendly ways of continuing monitoring noise and vibration in the zone site. Bridge consists of six among the distance between the columns, the total length of 929m, with major support system, a concrete pylon, which will consist of circular sections, the total height of 200m and foundations 25-30m below the river bottom Save with asymmetric bearing cables in the range of 376m and 200m, and still four sections in the range of 69m, 108m, 81m and 81m. The total width of the bridge is 45.04 m, with six lanes in both directions for automobile traffic, the two new rail routes and two pedestrian-bike paths. Schematic layout of the projected bridge, shown in Figure 1. [1]

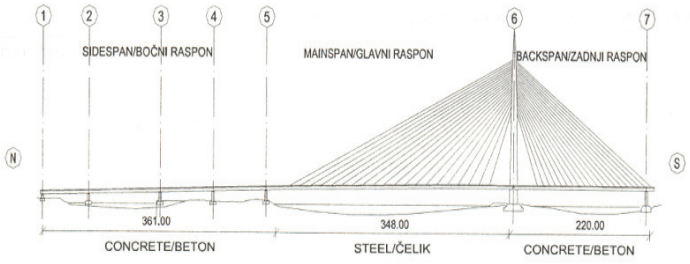


Fig. 1 *Schematic layout of the new Sava bridge in Belgrade- „Bridge at Ada”*

Fig. 2, shows the satellite view of traffic approaching the disposition of the loop, left and right sides of the river Sava, whose construction is underway, with the peak at Ada river, where he built the pylon.

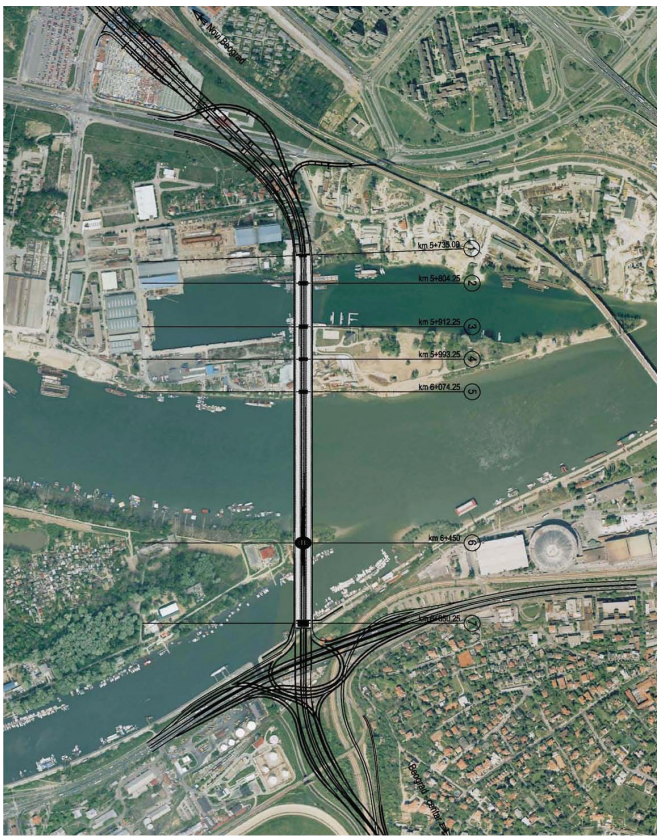


Fig. 2 *Location of the bridge and look of the traffic loops on the left and right coast of the Sava river [1]*

3.CONDITIONS AND MANNER OF DETERMINING NOISE MONITORING

Define the problem monitoring of noise during construction of the bridge, was realized through the implementation of the two procedures. The first procedure, preparation of noise maps, to determine the optimal level of border zones in residential, day and night. Noise measurement was carried out by software company IMMI 6.4 "Wolfel - Measurement - Software", complies with ISO and RVS 04:02:11 9613th

Second procedure included the implementation and emphasizing areas with the highest level of noise emission, so that in case of exceeding the calculated values of noise levels, it seemed timely.

The human sense of hearing is less sensitive to low and high frequency of mid-range sound. Under the same intensity, which means the same amount of energy or level, audible low-frequency noise, the noise is less than 2 kHz. The weighted noise level is measured and calculated on the basis of the characteristics of the human senses. The result is the sum of the height of which is called A-weighted "weighted" sound levels (dB(A)). In practice it is sometimes impossible to measure the basic level of noise. In this case the basic level of noise is replaced by the L_{95}, which is the noise level exceeded 95% during the duration of the measurement.

Energy equivalent continuous sound level (L_{eq}), the most commonly used procedure used to determine the average time variable noise, and calculate a noise level which is the energy equivalent of the constant effect of intermittent exposure to noise or noise with intermittent sound pressure level.

EU Directive "Assessment and Management of environmental noise ", a basic principle of the European approach to reduce noise impacts including the adverse effects of environmental noise. This concept introduces the strategic noise maps that represent the fundamental basis for the preparation of local action plans. Directive establishes two noise indicators to be applied in all Member States of the European Union. The first indicator, called L_{den} (day, evening and night), describes the current situation regarding the noise level of noise during the day. In order to describe the particular problems such as sleep binge use is another indicator L_{night}.

Day, evening and night levels (L_{den}), based on the application of EU directives, "Assessment and management of environmental noise" . It is a day-evening-night level which determines the average noise exposure during the day, also expressed in decibels (dB(A). During the evening hours, is added to 5 dB(A), and during the night, 10 dB(A).

In accordance with ISO 1996-2:1987, L_{den} indicator, the A-weighted equivalent continuous sound level of energy no matter what period evaluation last year and is calculated for each calendar day time period for day, evening and night. Denotes the average value of interference noise. Value, L_{den}, is correlated with danevno-night level (L_{dn}). Indicator, L_{dn}, is calculated for a period of 24 hours, and during night hours (22:00 to 6:00), with an additional 10 dB(A) which are taken into account.

$$L_{den} = 10x\lg\left(\frac{1}{24}x\left(13x10^{\frac{L_{day}}{10}} + 3x10^{\frac{L_{evening}+5}{10}} + 8x10^{\frac{L_{night}+10}{10}}\right)\right)$$

These indicators are used to plan and find a common approach to residential areas, towns or larger spaces. Field research has been applied to a large extent, placing special emphasis on problems and sleep disorders. The intensity of noise is calculated using a software firm IMMI 6.4 "Wolfel-Measurement - Software", in accordance with ISO and RVS 04:02:11 9613th. Due to the presence of a large number of parameters to be considered for take every exposed point, calculations were performed by computer program, which is consistent with the above mentioned requirements and ISO RVS 04:02:11 9613th. [3]

3.1. Weather conditions noise monitoring

Traffic noise is not constant noise, but it is variable from time to time at any place. Therefore, traffic noise described as energetically equivalent continuous sound level L_{eq}. The highest noise levels are neglected in the evaluation of traffic noise, because in practice they rarely occur when the heavy traffic, for example, on the highways. Therefore, the energy equivalent continuous sound level L_{eq}, for the day-time evening and night, gives the average impact noise. In many countries, there are no specific limits for noise during the construction of buildings. In order to carry out evaluation of unacceptable levels of noise it is necessary to modify the local conditions affecting the sensitivity of the normal senses of healthy adults and normal sensitivity heard of a healthy child. But even in these conditions is quite subjective circumstances that do not fully define the limits definite integral proportions modifications, and specific values can be seen as benchmarks. concept of building a new Sava

bridge in principle was based so that the work is mainly taking place during the day (06:00 -22:00), except for the period of construction of the pylon, when the works because of its specificity inevitably had to be carried out during the night.

For tasks that are performed during the night (22:00 - 06:00), continuous noise should not have been greater than 50 dB(A) (L_{night}), and during the day (06:00 - 22:00), above 70dB(A).

During the phase of the project followed by the bridge of where it came to an increase in noise, with emphasis on the number and timing operation of construction machines (heavy machinery, pin grabber, excavators, loaders, compressors, vehicles, etc.), which resulted in the determination of the axis of the measuring points in the day, the month and year of construction. In this way it is defined 7 (seven), measuring axis (axle 1.2 ... 7), which, depending on the needs of the total had about 12 (twelve) measuring points (IP 1.2 ... 12); shown in Figures 3,4,5,6,7,8.

For the calculation of noise impact on the worst cases were taken, taking into account a number of machines and their average use, with use of seven steps:

1.Concrete foundation and all seven axes, which are the basis for the foundation - piers and pylon, whose works were carried exclusively by day.

2. The construction of the pylon as the highest point of the bridge, was erected on the axis 6, whose works have lasted day and night.

3. Setting supporting pillars (pillar 1 to 7). The works lasted only during the day. (Table 1)

Table 1. *Construction equipment, L_W and average utilization (pylon construction site)*

PYLON							2009	2010.		
Source of Emissio.	onstructi -on equipme- nt	L_W (dB(A)	Height of Emissio n m)	Day %	Eveni- ng %	Night %	Nov	Feb	Apr	Sept.
S2	Compa -ctor	10 2	1	100%	100	70	2	2	2	2
S5	Compr- essor	10 0	1	80	80	70	2	2	2	2
S6	Concrete pump	10 9	1	100	100	15	2	2	2	2
S7	Power unit	90	1	100	100	70	2	2	2	2
S8	Truck	10 6	1,5	100	100	-	15 0	1 2 5	10 0	75
S11	Circular saw	10 4	15	50	50	-	2			
S12	Circular saw	10 4	60	50	50	-		2		
S13	Circular saw	10 4	90	50	50	-			2	
S14	Circular saw	10 4	160	50	50	-				2
S22	Grinders	10 0	15	80	80	-	3			
S22	Grinders	10 0	60	80	80	-		3		
S22	Grinders	10 0	90	80	80	-			3	
S22	Grinders	10 0	160	80	80	-	1			3
S15	Crane	98	15	100	100	70		1		
S16	Crane	98	60	100	100	70			1	
S17	Crane	98	90	100	100	70				1
S18	Crane	98	160	100	100	70				

4. Last range demanded setting up a platform for launching the axis 7, elements of 15-30m long, up to a final position. The works were carried out mostly during the day and night to use equipment that emits low noise level.

5. Lateral range is anchor on column 5 and slipped towards the sixth column. Last range is located near populated areas, a lateral range is in the middle of the river Sava. Completion of task 5, the lateral range is performing last arm, which is the 19th element The works were carried out mostly during the day.

6. The main range is one of the most important steps in the construction of the steel parts which are connected to the bridge piers. These works have lasted only a day.

7. Additional works are included, all necessary works which were necessary before the start of the bridge to traffic (setting asphalt layers on the steel bridge using the machine for paving, installation of bridge railings, installation of traffic signs and other safety equipment, etc..). The task was carried out on the entire surface of the bridge, while the site just over a day. [4,5]

4. SELECTION OF RELEVANT MEASURING POINTS

In order to select relevant measurement of noise impact zone and the time given the dominant influence of noise in the vicinity. Determined by the twelve measuring points divided in three locations around the site of the bridge over the Sava River. From IP1 to IP4 (taverns, no residential houses) are located on a small island called "Ada Ciganlija", the sixth axis IP1 is located closest to the axis 6 in order to obtain the highest sound pressure level in this zone. IP10 and IP5 are the "Belgrade Fair" which is populated zones. On the opposite side of the "Belgrade Fair" are IP11 and IP12 on a small island on the left side of the river Sava. Each of these measuring points sound pressure level is at calculatedn a height of 1.5 m and 6 m (IP5, IP6, IP7, IP8, IP10 and IP9). (Table 2). [2]

Table 2. Calculated noise levels, may 2009-L_{day}, $L_{evening}$, L_{night}, L_{den} (dB(A)).

May. 2009.-Noise emission [dB(A)]						
IP	eight (m)	L_{day} (06-18)	$L_{evening}$ (18-22)	L_{night} (22-06	L_{den}	L_d (16h)
IP1	1,5	62,3	62,3	47,2	63,0	62,3
IP2	1,5	59,3	59,3	43,5	59,8	59,3
IP3	1,5	54,1	54,1	40,5	54,9	54,1
IP4	1,5	56,3	56,3	44,3	57,4	56,3
IP5	6	56,4	56,4	39,3	56,9	56,4
IP5	1,5	56,2	56,2	37,1	56,5	56,2
IP6	1,5	59,5	59,5	45,8	60,2	59,5
IP6	6	59,2	59,2	45,4	60,0	59,2
IP7	1,5	61,4	61,4	48,8	62,3	61,4
IP7	6	61,1	61,1	48,4	62,0	61,1
IP8	6	61,9	61,9	49,9	62,9	61,9
IP8	1,5	61,5	61,5	49,5	62,5	61,5
IP9	6	59,0	59,0	44,5	59,6	59,0
IP9	1,5	57,9	57,9	42,5	58,4	57,9
IP10	6	55,6	55,6	42,6	56,5	55,6
IP10	1,5	55,5	55,5	42,4	56,3	55,5
IP11	1,5	58,3	58,3	38,6	58,5	58,3
IP12	1,5	57,1	57,1	38,6	57,4	57,1

Based RVS 04:02:11 (traffic) and ISO 9613 (construction equipment), the propagation of noise is calculated using the

IMMI 6.4 software product "Wolfel-Messszsteme-Software", which is on the market about 15 years and is suitable for professional use of target groups, such as public instucije, engineering offices, industry, etc. ..

When calculating, the parameters are set to screen resolution of 25m, and the outside temperature at 100^0C and 70% relative humidity. All the buildings around are defined as a reflexive (ρ=1-α =0.8). Absorption of the ground is set to G=0.8, and absorption of the natural environment is taken into consideration (green space, land, etc..). Under conditions of intense traffic, it is taken general speed limit of v=50 km/h. [2]

Maps noise given in Fig. 3,4,5, 6,7,8,9 and 10, are defined as a graphical representation of the calculated noise levels in certain areas. The difference between the noise level of different values, defined by different colors, where they expressed high levels of noise are marked with red, otherwise green and other colors of the spectrum.

On all maps show height measurement was fixed at 4m, and as a result of noise levels in during construction, the indicator L_{day}, defining the frequency, A-weighted sound pressure levels during the day, and noise maps for the noise indicator L_{night}, A-weighted level of bile pressure during the night.

5.RESULTS AND ANALYSIS NOISE MONITORING

Results calculated noise have been conceived and presented in a table that shows the month of the year in which the influence of noise in the evening, taking into account the different phases of construction. highest level of noise impact during the day (L_{day}), occurs in May 2009th, the IP1 test point at a height of 1.5 m is 62.3dB(A). The value is lower than the recommended value of the impact of noise is 70dB(A) during the day.

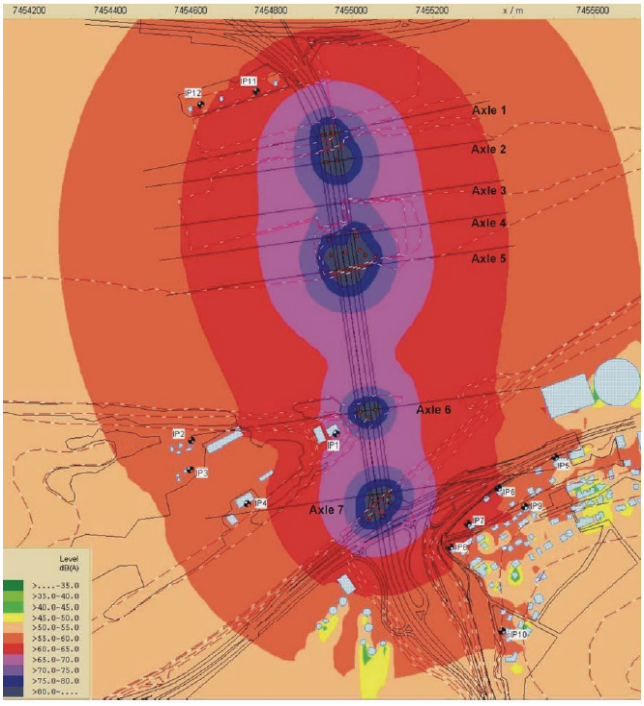


Fig. 3: Map of noise in the bridge zone [2]
(May. 2009, L_{day} [dB(A)], h = 4m)

Values in the evening ($L_{evening}$), are similar to those listed above. evening uiticaja level of noise during the night (L_{night}), occurs during the construction of the pylon (February 2010 to September 2010), the IP1 at a height of 1.5 m, and is 52.4 dB(A).

However, it must be emphasized that the IP1, is the tavern where no residential facilities. Taking into consideration the total period of construction and the impact on all other measuring points, at night, the calculated values are lower than the recommended value, 50 dB(A).

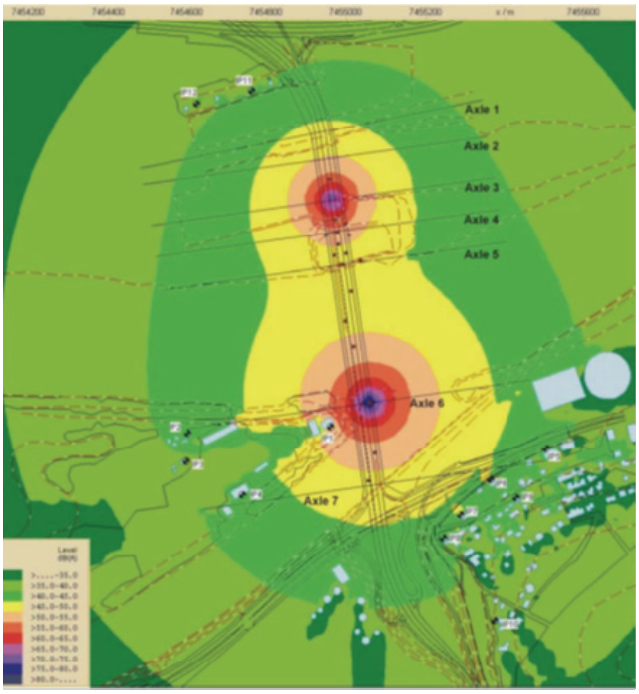


Fig. 4: Map of noise in the bridge zone
(May. 2009, L_{night} [dB(A)], h = 4m)

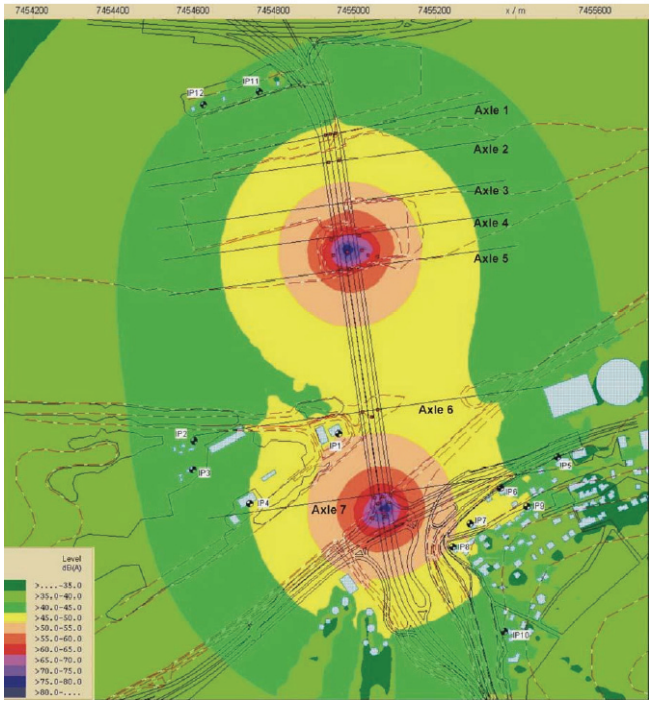


Fig. 5: Map of noise in the bridge zone
(July. 2009, L_{night} [dB(A)], h = 4m

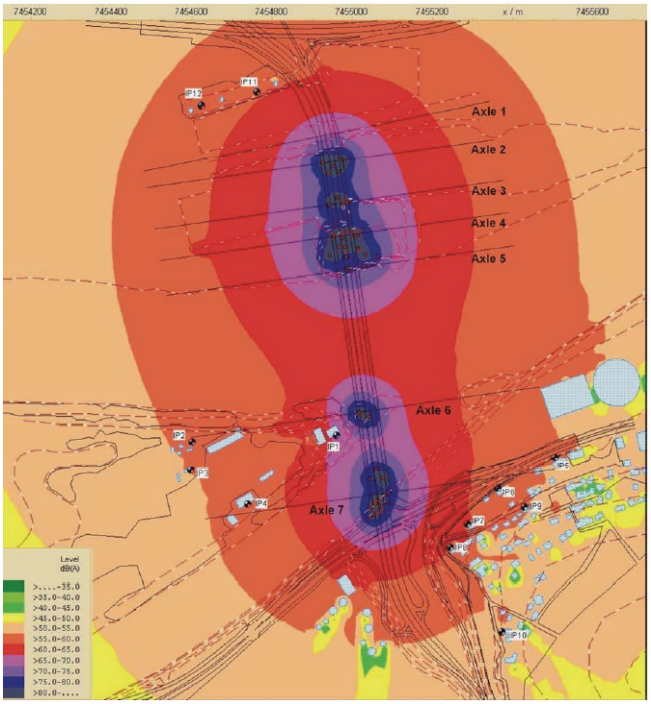


Fig. 6: Map of noise in the bridge zone
(September. 2009, L_{day} [dB(A)], h = 4m)

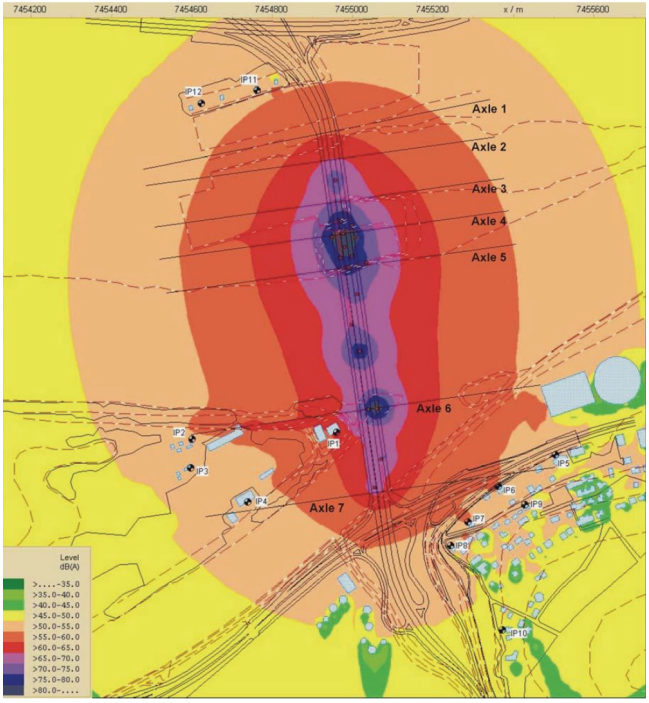


Fig. 8: Map of noise in the bridge zone
(September. 2009, L_{night} [dB(A)], h = 4m)

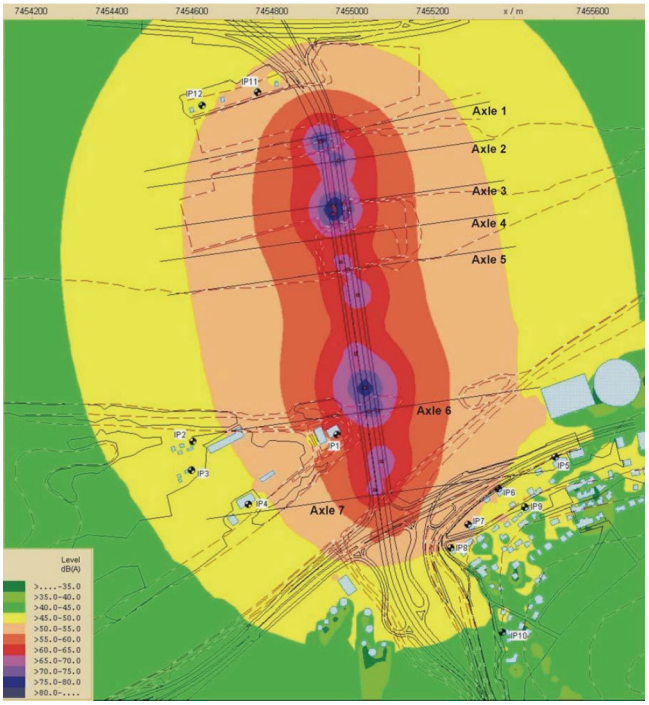


Fig. 7: Map of noise in the bridge zone
(January. 2009, L_{day} [dB(A)], h = 4m)

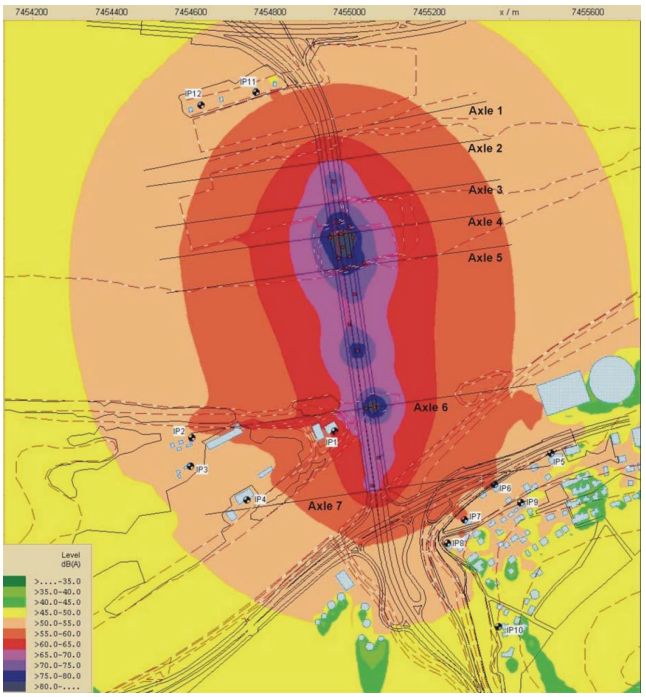


Fig 9. Map of noise in the bridge zone
(Septembre. 2010, L_{day} [dB(A)], h = 4m)

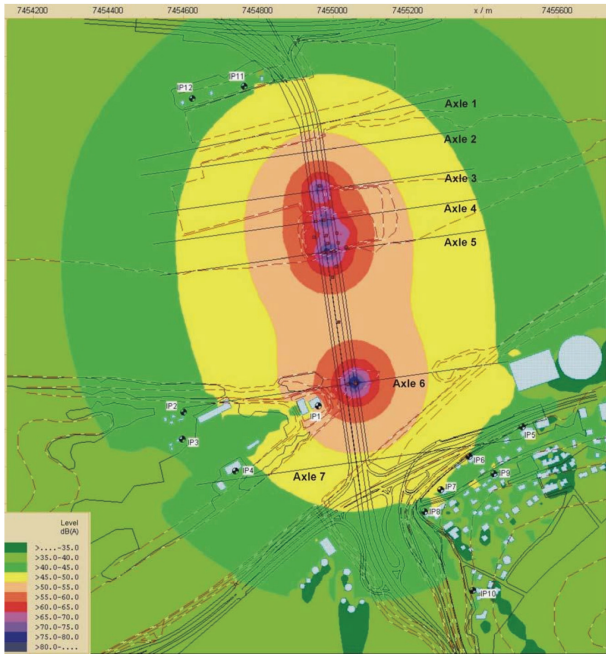


Fig 10. Map of noise in the bridge zone (April. 2010, L_{night} [dB(A)], h = 4m)

6. CONCLUSION

In determining the level of noise in the area of building a new Sava bridge-"Bridge of Ada", it is important to note that the terms depending on the selection and type of work, then time of day, month and year, conditional on the change in noise level, which was above the recommended - the permitted level. Based on these findings can be drawn the following conclusions.

- Noise maps are made for the purpose of determining the guaranteed optimal level of noise during the construction of monthly, day and night time work depending on the course of construction.
- There is no consistent noise restrictions during construction, because the levels of restrictions the only rappers.
- During construction at night (22:00- 06:00), continuous noise should not be higher than 50dB(A), (L_{night}), and during the day (06:00 to 22:00), a continuous noise level does not to be administered by 70dB(A), (L_{day}).
- The relevant measuring points were selected based on the dominant influence of noise in the vicinity with special emphasis on populated areas.
- The highest level of noise impact during the day (L_{day}), occurs in May 2009, the IP1 test point at a height of 1.5m is 62.3dB(A). The value is lower than the recommended value of the impact of noise is 70dB(A), during the day during construction.
- This means that during the entire construction of the bridge over the Sava River to calculate levels of the day (L_{day}), as well as during the evening ($L_{evening}$), meet the required value of 70dB(A) at all measuring points.
- However, it must be emphasized that the IP1, located near the restaurant and there are no residential buildings. Taking into account the total period of construction and the impact on all other measurements of the calculated values are lower than the recommended value that is 50dB(A) at night.
- The calculated site noise monitoring should be implemented with special emphasis on areas with the highest noise emissions to verify the results of the noise maps.
- If the measured noise level (in the construction zone), was higher than the calculated noise levels, the contractor should take adequate measures to reduce noise. [2]

REFERENCES

[1] Petrovic P., Mirović R., Maravić B.: "*The ecological aspect of noise and vibration in the area construct a new bridge across the Sava River",* (XXII Conference with international participation "Noise and Vibration", Niš, 2010., Faculty of Occupational Safety, p.29-34

[2] Jaksch M., Kalivoda M.T.: "*The noise during the construction works-bridge across the Sava river in Belgrade"*, Report "psiA Consult ", Umweltforschung und Engineering GmbH, Lastenstrase 38, A-1230 Wien, DN 2009-367-006-1 to 39

[3] Petrovic P., Jovanovic T., Marija Petrovic, Mirović R., Tomic R.:, *"Prediction of traffic noise, with emphasis on the new tram bridge and the possibility of protection of settlements by placing acoustic panels,"* , (I- important scientific-technical conference "Corridor 10"-sustainable path integration, 2010., Belgrade, Business policy, Belgrade, Chamber of Commerce, Institute "Kirilo Savić", (pp. 144-163).

[4] Petrović P.: „*The generation of noise diesel engine",* Monografy, SITS, Institute Kirilo Savić, 2009. Belgrade, Serbia

[5] Bruel&Kjaer*:"PULS Order Analysis*", with PULSE Multi- analyzer version 4.2,CD, Multimedia Presentation.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

ENVIRONMENTAL NOISE AS THE HAZARD IN THE ENVIRONMENT OF THE CITY OF NOVI SAD

Živadinović Emil[1], Bijelović Sanja[1,2], Dragić Nataša[1], Popović Milka[1,2], Milosević Siniša[1], Lalović Zivojin[1]

[1]Institute of Public Health of Vojvodina (IPHV)
[2] University of Novi Sad, School of Medicine

1. INTRODUCTION

The aim of work is to identify the environmental noise as the hazard [1] in the environment of Novi Sad due to values of total (L_{den}), day (L_{day}), night (L_{night}) end evening ($L_{evening}$) level of noise [2].

2. METHODOLOGY

During 2011 there were done 81 24-hours measurements of basic noise indicators during the April-December and 162 15-minutes measurements of equivalent noise level during the January-March. Measurements were originated from IPHV [3] due to standardised and accredited methodology [4, 5]. Percentage of increased noise level is estimated using annual average of basic noise indicators. Percentage of annoyed (%A) and highly annoyed population (%HA) are estimated by equal [4, 6].

In this work there were used 16 noise measuring points from noise monitoring network in the city of Novi Sad classified due to urban space purpose [7] (Table 1).

Table 1 *Measuring pointsin the noise monitoring network*

Urban space purpose	Measuring point
Resting and recreation areas, hospital and rehabilitation areas, cultural and historical sites, major parks	1. Sajmište
Residential areas	1. Podbara 2. Nova Detelinara 3. Novo Naselje 4. Telep 5. Kej 6. Ulica cara Dušana 7. Petrovaradin
City Centre, craft, trade and administrative areas with apartments, roads, highways and city street zones	1. „SPENS“ 2. Bulevar Mihajla Pupina 3. Bulevar oslobođenja 4. Rumenačka ulica 5. „GRAS“ 6. Futoška ulica 7. Liman III
Industrial, storage and service areas, tranport terminals without apartments	1. Partizanska ulica

3. RESULTS

During 2011, due to established measuring points, annual average of basic noise indicators (daily, evening and night) is the lowest in "Residential areas" and the highest in "City Centre, craft, trade and administrative areas with apartments, roads, highways and city street zones". Due to established measuring points, value of L_{day} varies from 59.6 dB(A) to 70.3 dB(A), value of $L_{evening}$ varies from 55.8 dB(A) to 69.4 dB(A), value of L_{night} varies from 50.2 dB(A) to 64.5 dB(A) and value L_{den} varies from 60.3 dB(A) to 72.9 dB(A) (Table 2).

Table 2 *Annual average of basic noise indicators due to established measuring points in the city of Novi Sad in 2011*

Urban space purpose	Measuring point	L_{day} dB(A)	$L_{evening}$ dB(A)	L_{night} dB(A)	L_{den} dB(A)
Resting and recreation areas, hospital and rehabilitation areas, cultural and historical sites, major parks	Sajmište	61.9	61.9	57.3	65.3
Residential areas	Podbara	59.6	57.9	52.0	61.3
	Nova Detelinara	61.4	56.3	55.6	64.4
	Novo Naselje	59.8	55.8	50.2	60.3
	Telep	66.1	65.3	60.2	68.7
	Kej	68.5	67.1	62.6	71.1
	Ulica cara Dušana	69.0	68.0	63.3	71.6
	Petrovaradin	65.9	64.3	60.1	68.3
City Centre, craft, trade and administrative areas with apartments, roads, highways and city street zones	„SPENS“	66.6	64.2	62.3	70.2
	Bulevar Mihajla Pupina	65.4	64.7	59.9	68.3
	Bulevar oslobođenja	64.5	64.4	61.3	68.7
	Rumenačka ulica	70.3	69.4	64.5	72.9
	„GRAS“	65.3	64.4	60.4	68.3
	Futoška ulica	65.3	64.4	60.5	68.5
	Liman III	65.0	65.2	61.1	68.9
Industrial, storage and service areas, tranport terminals without apartments	Partizanska ulica	67.3	65.9	63.0	70.5

During 2011, due to urban space purpose, average of basic noise indicators (daily, evening and night) is the lowest in "Resting and recreation areas, hospital and rehabilitation areas, cultural and historical sites, major parks" and the highest in "Industrial, storage and service areas, tranport terminals without apartments". Due to urban space purpose value of L_{day} varies from 61.9 dB(A) to 67. 3dB(A), value of $L_{evening}$ varies from 61.9 dB(A) to 65.9 dB(A), value of L_{night} varies from 57.3 dB(A) to 63.0 dB(A) and value of L_{den} varies from 65.3 dB(A) to 70.5 dB(A) (Table 3).

Table 3 *Annual average of basic noise indicators in 2011*

Urban space purpose	Annual average			
	L_{day} dB(A)	$L_{evening}$ dB(A)	L_{night} dB(A)	L_{den} dB(A)
Resting and recreation areas, hospital and rehabilitation areas, cultural and historical sites, major parks	61.9	61.9	57.3	65.3
Residential areas	64.3	62.1	57.7	66.5
City Centre, craft, trade and administrative areas with apartments, roads, highways and city street zones	66.1	65.2	61.4	69.4
Industrial, storage and service areas, tranport terminals without apartments	67.3	65.9	63.0	70.5

The annual average of L_{day} is increased for 23.80% in resting and recreation area and for 22.36% in industrial area, with statistical significance ($p<0.01$) respectively, while there is no statistical significance ($p>0.05$) with elevated annual average of L_{day} in city center (Table 4).

Table 4 *Daily percentage of increasing*

Urban space purpose	Annual average L_{day} dB(A)	*Limit value* dB(A)	*% of increasing*	*"p" value*
Resting and recreation areas, hospital and rehabilitation areas, cultural and historical sites, major parks	61.9	50	23.80	p<0.01
Residential areas	64.3	55	16.96	p<0.05
City Centre, craft, trade and administrative areas with apartments, roads, highways and city street zones	66.1	65	1.63	p>0.05
Industrial, storage and service areas, tranport terminals without apartments	67.3	55	22.36	p<0.01

The annual average of $L_{evening}$ is increased for 23.80% in resting and recreation area and for 19.82% in industrial area, with statistical significance ($p<0.001$) respectively, while there is no statistical significance ($p>0.05$) with elevated annual average of $L_{evening}$ in residential areas and in city center (Table 5).

Table 5 *Evening percentage of increasing*

Urban space purpose	**Annual average $L_{evening}$ dB(A)**	***Limit value* dB(A)**	***% of increasing***	***"p" value***
Resting and recreation areas, hospital and rehabilitation areas, cultural and historical sites, major parks	61.9	50	23.80	p<0.01
Residential areas	62.1	55	12.91	p>0.05
City Centre, craft, trade and administrative areas with apartments, roads, highways and city street zones	65.2	65	0.37	p>0.05
Industrial, storage and service areas, tranport terminals without apartments	65.9	55	19.82	p<0.001

The annual average of L_{night} is increased for 43.25% in resting and recreation area, for 28,25% in residential areas and for 40.00% in industrial area, with statistical significance ($p<0.001$) respectively, while there is no statistical significance ($p>0.05$) with elevated annual average of L_{night} in and in city center (Table 6).

Table 6 *Nightly percentage of increasing*

Urban space purpose	Annual average L_{night} dB(A)	*Limit value* dB(A)	*% of increasing*	*"p" value*
Resting and recreation areas, hospital and rehabilitation areas, cultural and historical sites, major parks	57.3	40	43.25	p<0.001
Residential areas	57.7	45	28.25	p<0.001
City Centre, craft, trade and administrative areas with apartments, roads, highways and city street zones	61.4	55	11.69	p>0.05
Industrial, storage and service areas, tranport terminals without apartments	63.0	45	40.00	p<0.001

During 2011, in the recreation areas %A / %HA were 36% / 17% during day and 20% / 10% during night, in the residential areas 39% / 19% during day and 20% / 10% during night, in the city center and trade areas 46% / 24% during day and 25% / 12% during night and in the industrial and services areas 48% / 26% during day and 27% / 14% during night (Table 7, 8).

Table 7 *Percentage of annoyed / highly annoyed people by day*

Urban space purpose	Annual average L_{den} dB(A)	%A	%HA
Resting and recreation areas, hospital and rehabilitation areas, cultural and historical sites, major parks	65.3	36.12	16.61
Residential areas	66.5	38.83	18.48
City Centre, craft, trade and administrative areas with apartments, roads, highways and city street zones	69.4	45.60	23.54
Industrial, storage and service areas, tranport terminals without apartments	70.5	48.36	25.77

Table 7 *Percentage of annoyed / highly annoyed people by night*

Urban space purpose	Annual average L_{night} dB(A)	%A	%HA
Resting and recreation areas, hospital and rehabilitation areas, cultural and historical sites, major parks	57.3	19.93	9.42
Residential areas	57.7	20.37	9.70
City Centre, craft, trade and administrative areas with apartments, roads, highways and city street zones	61.4	24.60	12.37
Industrial, storage and service areas, tranport terminals without apartments	63.0	26.53	13.63

4. CONCLUSION

According to determined values, noise is the hazard in the environment of city of Novi Sad, and, therefore, can couse adverse effect to human health. Percentage of increased noise level during day, evening and night is the highest in the recreation areas, while, at the same time, percentage of annoyed and highly annoyed population is the least in the same area. This work indicate a strong need of interviewing the population by standardize queries for annoyance and sleep disturbance. Regarding our results, the city administration has approved to IPHV this year the investigation of annoyance and sleep disturbances among citizens. Results will be published in the future.

REFERENCES

[1] World Health Organization, Regional Office for Europe and JRC European Commission. Burden of disease from environmental noise, WHO, 2011.

[2] Directive 2002/49/EC of The European Parliament and of The Council.

[3] Institut za javno zdravlje Vojvodine, "Izveštaj o nivou buke u životnoj sredini Grada Novog Sada tokom 2011. godine", januar 2012. godine.

[4] Akustika – Opis, merenje i ocenjivanje buke u životnoj sredini – Deo 1: Osnovne veličine i postupci ocenjivanja, SRPS ISO 1996-1:2010.

[5] Akustika – Opis, merenje i ocenjivanje buke u životnoj sredini – Deo 2: Određivanje nivoa buke u životnoj sredini, SRPS ISO 1996-2:2008.

[6] Uredba o indikatorima buke, graničnim vrednostima, metodama za ocenjivanje indikatora buke, uznemiravanja i štetnih efekata buke u životnoj sredini, Sl. glasnik br. 75/2010.

[7] Generalni plan Grada Novog Sada do 2012. godine, Službeni list Grada Novog Sada broj 39/2006.

UNIVERSITY OF NIŠ
FACULTY OF OCCUPATIONAL SAFETY

STUDY PROGRAMS

Faculty of Occupational Safety in Niš
organizes Basic Academic Studies under the program

OCCUPATIONAL AND ENVIRONMENTAL SAFETY

Basic academic studies last for three (3) years, with the range of 180 ECTS points.
A student who finishes this study program acquires the title of
BACHELOR OF SCIENCE IN ENVIRONMENTAL SAFETY.

Faculty of Occupational Safety in Niš
organizes Master Academic Studies at five study programs:

OCCUPATIONAL SAFETY

FIRE PROTECTION

ENVIRONMENTAL SAFETY ENGINEERING

EMERGENCY MANAGEMENT

COMMUNAL SYSTEM MANAGEMENT

Master Academic Studies last for two (2) years, with the range
of 120 ECTS points. A student who finishes one of these study programs
acquires the academic title -
MASTER OF SCIENCE in the corresponding area.



REPUBLIC OF SERBIA, Čarnojevića 10A, 18000 Niš
Phone: 381 18 529701, 381 18 529-805, 381 18 529 755, Fax: 381 18 249 962
www.znrfak.ni.ac.rs

University of Nis
Faculty of Occupational Safety

„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

AN ANALYSIS OF THE ENVIRONMENTAL NOISE LEVELS ON THE TERRITORY OF THE CITY OF NIŠ

Darko Mihajlov[1], *Momir Praščević*[1], *Dragan Cvetković*[1]

[1] University of Nis, Faculty of Occupational Safety, Serbia; darko.mihajlov@znrfak.ni.ac.rs

Abstract - *The communal noise level represents one of the key factors of life quality in urban areas. A continuous monitoring of the noise levels and the analysis of results have become a necessity when we discuss a possible recovery of those areas with high levels of noise pollution, and particularly those zones which were designed for specific activities. The city of Niš, Serbia, owing to the permanent long-term noise monitoring, possesses a database containing figures related to the noise levels at relevant locations in the city, which can serve as a basis for an analysis of the change of conditions, their tendencies in the future and recognizing factors which influence the danger of noise pollution.*

The paper involves an analysis of the noise level at a number of characteristic locations in the city of Niš during the previous three years.

1. INTRODUCTION

Noise pollution represents a major problem in the environment of most urban areas. However, the problem of noise has not been approached properly so far, and not enough attention has been paid to it in spite of the fact that it has a great impact on the quality of life of the endangered population. Reasons for such an approach could be found in the very definition of noise as a subjective experience of various external events, in its specific character, as well as in the difficulties connected to relating the causes with the effects it has on general health.

The results of medical studies have shown that noise can have very adverse effects on human health and justify the need for further explorations aiming at a better understanding and an improved control over noise. Namely, noise is treated as a serious health threat, with consequences ranging from anxiety to death and it is considered to be one of the main causes of stress, which has a psycho-social component. Practical effects of noise on people usually manifest themselves as unpleasant feelings, lack of concentration, sleep disorders and stress caused by ischemic heart disorders. It is extremely important to evaluate the impact which noise has on child health and development, as it can cause speech impairments and decrease learning capabilities.

Along with health issues, some recent studies in the field have also stressed various economic impacts of noise pollution. Besides the resources invested in preventing noise in populated areas near traffic arteries, airports, railroads and highways or other noise sources (e.g. industrial), recent studies have analysed the healthcare expenses related to treating disorders which emerge in noise-polluted areas. Moreover, the level of communal noise pollution has a great economic impact on real estate prices in residential and business areas. Studies have shown that traffic noise cause a 5% drop in real estate prices on the average, and that the percentage can go up to 12% in the times of economic growth. This fact stimulated researchers from all around the world to dedicate more time to studying and defining the issue of traffic noise.

Traffic definitely represents the dominant source of communal noise and the main cause of disturbance and anxiety in people. Around 120 million people in the European Union are exposed to the levels of road traffic noise higher than 55 dB(A), whereas 50 million of them are exposed the levels of road traffic noise higher than 65 dB(A). If we take into consideration the fact that the level of noise of above 55 dB(A) causes unpleasant feelings, aggressive behaviour and sleep disorders, that permanent exposure to the level of noise of above 65 dB(A) can cause hypertension and that permanent exposure to the level of noise of above 75 dB(A) leads to higher stress levels, increases the number of people with heart disorders and can lead to hearing damage, it becomes clear that traffic planning and protecting inhabitants of urban areas from traffic noise require a far more serious approach.

The conditions related to noise pollution in the city of Niš are in many ways similar to conditions in other urban environments. Collecting information on traffic characteristics and updating it over a longer period has proven to be crucial to the evaluation and management of communal noise in an environment. Furthermore, measurement and evaluation of traffic noise are important activities which may result in the development of efficient methods for its control.

The city of Niš belongs to the group of medium-sized cities, with around 300,000 inhabitants. During the past decades it has been growing and taking up more territory, which has been followed by numerous changes in regard to urbanization, industrialization, having a larger traffic network and greater infrastructure. Recently, the city has been particularly exposed to an increased frequency of road traffic, which, in the given circumstances of traffic infrastructure, represents a crucial factor in the increase of noise pollution. Given the average age of cars in Serbia (11 years old) and the average age of public transport buses (15 years old), we can get a preliminary picture of the main sources of communal noise on the territory of the city of Niš. Conditions related to communal noise at specific spots in the city and their levels of noise pollution depend on a number of factors, such as: the

type of vehicles taking part in traffic, passing frequency of specific vehicles on specific roads during referential periods, road characteristics (its width, the number of lanes, whether it is a one-way or a two-way road, a boulevard, the type and quality of the surface, its slope), movement speed, presence of specialized or natural sound barriers (greenery along the road, parks, etc.) between the road and the area of interest.

Data on noise levels in the city of Niš have been systematically collected and analysed through the project of monitoring the noise level during a number of years. The obtained results give us an insight into the current condition of the noise level at specific locations, allowing us to compare them to previous measurement results and use this to evaluate tendencies related to possible changes in the future.

2. RESEARCH METHODOLOGY

The city of Niš, as a unit of local autonomy, represents a subject in the system in environmental protection from noise and, as such, and in accordance with the existing laws and regulations, has the authority over providing continuous control and monitoring of the noise levels in its environment.

Noise monitoring is performed by means of systematic measurement, examination and evaluation of noise indicators - physical dimensions which describe noise in an environment and which are related to the adverse effects of noise.

2.1 The elements of environmental noise level monitoring

For the purpose of the noise level monitoring on the territory of the city of Niš, continuous measurements of the sound pressure level are performed and they define its time dependencies at 11 measurement locations within all five city municipalities. The choice of measurement spots was done in accordance with location purpose zones, resulting in the selection of measurement spots which includes:

- Leisure and recreation areas, hospital zones, cultural and historical spots, large parks;
- Tourist areas, small settlements and villages, camps and school zones;
- Purely residential districts;
- Combined business and residential districts, combined commercial and residential districts and playgrounds;
- The city centre, craftsman, commercial and administrative areas with housing, zones along highways, main roads and city traffic arteries.

The locations of measurement spots as related to nearby objects and roads were defined in accordance with the SRPS ISO 1996 standard. The noise level monitoring on the territory of the city of Niš is organized on a monthly basis, for the referential time intervals: day (06:00÷22:00) and night (22:00÷06:00). The procedure of continuous noise level monitoring lasts for 12 months (the long-time interval).

The measurement time intervals were chosen in such a way that they encompass the whole cycle of noise level changes during the referential time intervals. One measurement interval lasts for 15 minutes. The day measurement interval is divided into three periods (09:00÷12:00, 13:00÷16:00 and 18:00÷21:00), whereas the night measurement interval is divided into two periods (22:00÷01:00 and 02:00÷05:00), which means that during 24 hours there are five measurement periods. At each measurement spot, within one cycle/month, there is one measurement instance in each of the five measurement periods (table 1).

Table 1 *The dynamics of noise monitoring*

Long-time interval:	12 months (1 year)				
No. of series:	12 (monthly) - Three series of measurements for each of the 44 measurement points within 12 months				
Reference time interval:	Day 06:00÷22:00			Night 22:00÷06:00	
Time period:	09:00 ÷ 12:00	13:00 ÷ 16:00	18:00 ÷ 21:00	22:00 ÷ 01:00	02:00 ÷ 05:00
Measurement time interval:	15 min.	15 min.	15 min.	15 min.	15 min.

Monthly measurement dynamics involve defining the time dependencies of the current noise levels at 11 measurement spots within the defined measurement locations, which means 55 measurements of the noise parameters, accompanied by defining the traffic and road parameters. The procedure of noise level monitoring at each measurement spot is determined by the following measurement parameters:

- noise parameters (noise character, equivalent noise level, percental noise level, noise level time dependency);
- traffic parameters (passenger car frequency, light and heavy truck frequency, bus and motorcycle frequency);
- road parameters (the type and width of the road, the height of buildings along the road).

2.2 The aims of environmental noise level monitoring

The continuous noise level monitoring gives an insight into the actual noise levels in the environment on the territory of the city of Niš and, with all the data it provides, serves as the basis for putting into effect activities such as:

1. establishing and applying the measures and conditions for noise protection in those areas with noise levels above the limit;
2. acoustic zoning of the city's territory;
3. protection of "silent zones";
4. developing strategic noise maps;
5. developing a local action plan of environmental noise protection;
6. monitoring and controlling the implementation of environmental noise protection measures;
7. recognizing the problem of noise in spatial planning of the new and reconstructed settlements and other areas in accordance with the SRPS U.J6.205 standard.
8. providing and obeying the established technical rules which guarantee the quality of sound protection in accordance with the standard (the standards belonging to the group SRPS U.J6) in the process of building and issuing technical acceptance certificates for residential, investment and industrial objects, small enterprise objects and city infrastructure;
9. valorisation of residential areas with regard to the ways in which various ecological indicators can represent a risk to living conditions

3. RESEARCH RESULTS

The instrument made by Brüel & Kjær, Model 2250, was used for collecting the parameters for the purpose of noise monitoring. The detailed results of the noise monitoring for each analysed measurement spot in the period from 2009 until 2011 are given in the tables 2, 3 and 4, respectively. Using the obtained information, it is possible to perform a comparative analysis of the noise level at each analysed spot during the previous three years.

Table 2 *The noise monitoring results at the measurement spot 1*

Location and description of the measurement spot 1:		Nis / Dr Zoran Djindjic Boulevard / within the Clinical Center, in front of the Department of Internal Medicine - 15 m from the building and 4 m from the edge of the road;														
Use of the space:		Hospital zone														
Limited noise level for day and evening / night [dB(A)]:		50 / 40														
Dominant source of noise:		Road traffic														
The character of the noise:		Variable broadband noise														
The parameters of the road:		Two-way, two-lane per direction, width 10 m, speed limit 50 km/h														
Years of monitoring:		**2009.**					**2010.**					**2011.**				
Period of measurement:		09-12	13-16	18-21	22-01	02-05	09-12	13-16	18-21	22-01	02-05	09-12	13-16	18-21	22-01	02-05
No.of vehicles (15 min.)	Cars	361	305	339	172	36	357	445	296	154	38	320	365	265	128	23
	Light-duty vehicles	9	5	1	0	0	6	4	2	0	0	4	4	2	0	0
	Heavy-duty vehicles	1	0	0	0	0	1	1	0	0	0	1	1	0	0	0
	Buses	13	15	15	6	0	14	17	12	7	0	15	15	14	7	0
	Motorcycles	5	9	7	6	1	2	12	11	2	0	2	7	5	1	0
	Total	**389**	**335**	**362**	**185**	**37**	**381**	**479**	**321**	**163**	**39**	**342**	**392**	**285**	**136**	**23**
Measured noise level [dB(A)]	LAFmax	77.2	73.5	75.1	75.5	68.1	79.5	77.8	78.3	75.5	68.3	82.4	85.0	84.9	79.5	71.1
	LAFmin	47.0	47.9	48.6	40.8	32.6	47.9	50.7	49.5	41.5	34.2	52.4	55.0	50.7	44.1	36.3
	LAImax	78.7	74.9	76.7	78.2	69.3	81.1	80.3	79.8	76.6	69.7	79.5	82.2	80.7	76.9	68.8
	LASmax	73.9	71.6	72.8	71.4	66.5	75.8	74.8	73.9	72.9	66.3	83.5	87.1	86.8	81.2	72.5
	LASmin	47.8	49.1	49.8	41.9	33.3	49.1	52.0	50.4	42.4	35.3	53.6	56.3	51.9	45.1	36.9
	L1	70.3	69.3	70.0	67.2	63.3	71.1	71.1	69.1	69.3	63.6	75.8	76.0	75.3	74.2	66.1
	L5	66.5	66.2	66.9	63.3	57.6	67.0	67.7	66.6	65.4	59.7	70.7	70.7	70.9	69.6	61.5
	L10	64.9	64.8	65.3	61.6	55.7	65.5	65.9	65.4	63.8	57.4	68.8	68.9	69.0	67.5	57.8
	L50	60.3	60.8	61.1	55.8	43.7	61.4	61.5	61.2	57.8	44.3	64.1	64.6	63.9	59.3	44.2
	L90	54.7	55.9	55.4	47.7	35.5	55.6	57.3	56.4	48.4	36.7	58.9	60.7	57.8	50.2	38.6
	L95	52.7	54.1	53.2	45.8	34.4	53.4	56.0	54.9	45.4	36.1	57.3	59.5	55.6	48.7	38.0
	L99	49.2	50.9	50.7	42.5	33.4	50.6	53.4	51.9	43.3	35.1	54.8	57.5	52.8	46.4	37.1
	Leq	**62.1**	**62.0**	**62.4**	**58.4**	**51.9**	**62.9**	**63.2**	**62.5**	**60.5**	**53.0**	**66.4**	**66.9**	**66.3**	**63.9**	**54.1**
Exceeding the limit level [dB(A)]		**12.1**	**12.0**	**12.4**	**18.4**	**11.9**	**12.9**	**13.2**	**12.5**	**20.5**	**13.0**	**16.4**	**16.9**	**16.3**	**23.9**	**14.1**
Rating noise level [dB(A)]		**62**			**56**		**63**			**58**		**67**			**61**	
Exceeding the limit level [dB(A)]		**12**			**16**		**13**			**18**		**17**			**21**	

Table 3 *The noise monitoring results at the measurement spot 2*

Location and description of the measurement spot 2:		Nis / Vozda Karadjordja Str./ within the school "Vozd Karadjordje", in front of the main entrance to the school - from 6 m, and 4 m from the edge of the road;														
Use of the space:		School zone														
Limited noise level for day and evening / night [dB(A)]:		50 / 45														
Dominant source of noise:		Road traffic														
The character of the noise:		Variable broadband noise														
The parameters of the road:		Two-way, two-lane per direction, width 10 m, speed limit 30 km/h														
Years of monitoring:		**2009.**					**2010.**					**2011.**				
Period of measurement:		09-12	13-16	18-21	22-01	02-05	09-12	13-16	18-21	22-01	02-05	09-12	13-16	18-21	22-01	02-05
No.of vehicles (15 min.)	Cars	238	307	231	136	41	253	299	250	137	32	277	335	239	135	49
	Light-duty vehicles	3	3	1	0	0	4	2	0	0	1	4	2	1	0	0
	Heavy-duty vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Buses	11	16	12	6	0	12	17	12	7	0	10	15	14	5	1
	Motorcycles	4	9	8	7	1	3	13	8	1	0	3	14	7	1	0
	Total	**256**	**336**	**252**	**150**	**41**	**274**	**330**	**270**	**146**	**33**	**295**	**365**	**261**	**142**	**50**
Measured noise level [dB(A)]	LAFmax	84.4	82.7	84.1	83.2	77.3	82.2	85.3	85.8	79.5	77.1	83.9	93.7	87.0	87.8	77.7
	LAFmin	51.5	53.2	49.2	44.5	41.8	54.1	52.0	49.7	44.6	38.4	52.1	53.8	48.2	46.4	37.7
	LAImax	85.8	83.7	85.6	84.6	78.3	83.6	86.6	88.0	81.1	78.5	82.4	92.1	85.6	85.7	75.1
	LASmax	81.5	80.7	81.7	79.7	74.7	79.9	82.4	80.9	76.8	74.1	84.2	93.4	86.8	87.7	78.1
	LASmin	53.3	54.7	50.3	45.4	42.9	55.6	53.4	51.2	45.5	38.9	53.1	55.3	50.0	47.7	38.3
	L1	77.4	77.5	76.3	74.5	68.7	77.3	78.5	76.4	74.2	70.5	76.7	80.4	79.3	77.3	71.3
	L5	71.9	73.4	71.1	69.8	65.1	72.1	74.0	71.5	70.2	66.4	72.1	73.2	73.4	70.9	67.4
	L10	69.7	70.7	69.2	67.8	62.7	69.8	71.3	69.3	68.4	63.5	69.7	70.7	70.8	69.0	64.5
	L50	64.8	65.3	64.2	61.9	49.8	64.9	65.6	64.5	62.2	48.5	64.6	65.9	64.6	62.7	51.5
	L90	58.9	60.5	57.9	51.7	44.2	60.3	60.4	58.7	52.2	40.3	58.6	60.6	57.9	53.5	42.3
	L95	57.4	58.8	55.6	49.4	43.6	58.8	58.3	56.7	49.9	39.7	56.8	59.0	55.8	51.5	40.9
	L99	54.2	55.8	52.2	46.1	42.7	56.6	55.0	52.7	46.4	38.9	54.0	56.1	51.6	49.0	39.4
	Leq	**67.4**	**68.0**	**67.0**	**64.9**	**58.7**	**67.4**	**68.6**	**66.9**	**65.0**	**59.3**	**67.3**	**70.9**	**68.6**	**66.8**	**60.4**
Exceeding the lim. level [dB(A)]		**17.4**	**18.0**	**17.0**	**19.9**	**13.7**	**17.4**	**18.6**	**16.9**	**20.0**	**14.3**	**17.3**	**20.9**	**18.6**	**21.8**	**15.4**
Rating noise level [dB(A)]		**67**			**63**		**68**			**63**		**69**			**65**	
Exceeding the lim. level [dB(A)]		**17**			**18**		**18**			**18**		**19**			**20**	

Table 4 *The noise monitoring results at the measurement spot 3*

Location and description of the measurement spot 3:		Nis / Kralja Milana Square / the beginning of Milan Obrenovic street (pedestrian zone), in parallel with the residential-bussines building "Gorca" - 5 m from the building and 4 m from the edge of the road;														
Use of the space:		City center														
Limited noise level for day and evening / night [dB(A)]:		65 / 55														
Dominant source of noise:		Road traffic														
The character of the noise:		Variable broadband noise														
The parameters of the road:		Two-way, two-lane per direction, width 10 m, speed limit 50 km/h														
Years of monitoring:		**2009.**					**2010.**					**2011.**				
Period of measurement:		09-12	13-16	18-21	22-01	02-05	09-12	13-16	18-21	22-01	02-05	09-12	13-16	18-21	22-01	02-05
No.of vehicles (15 min.)	Cars	278	324	249	115	29	273	360	262	89	23	314	357	233	117	18
	Light-duty vehicles	6	1	0	0	1	3	1	1	0	1	3	1	1	0	1
	Heavy-duty vehicles	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0
	Buses	22	34	15	5	1	20	31	22	5	1	25	36	22	9	2
	Motorcycles	3	7	5	5	0	5	8	9	4	0	4	13	7	3	0
	Total	**310**	**366**	**270**	**125**	**31**	**302**	**401**	**294**	**99**	**26**	**346**	**408**	**263**	**130**	**21**
Measured noise level [dB(A)]	LAFmax	89.3	85.9	84.1	89.5	81.0	85.7	85.0	90.1	84.7	88.0	87.2	86.2	87.7	87.3	81.6
	LAFmin	57.0	59.2	56.9	47.0	39.1	54.8	58.0	54.4	47.3	40.3	56.0	58.8	55.1	51.6	44.5
	LAImax	91.7	87.7	86.8	91.0	82.4	87.3	86.0	91.9	86.0	89.3	84.5	83.3	84.0	83.7	79.6
	LASmax	84.6	82.9	80.2	86.1	78.8	83.2	82.8	86.6	81.5	84.7	88.5	87.0	89.0	89.6	83.0
	LASmin	58.4	60.2	57.9	48.6	39.9	56.2	58.8	55.5	48.0	41.0	57.3	59.9	56.2	52.6	44.9
	L1	80.0	80.8	77.7	78.5	74.4	81.4	79.3	81.2	76.2	73.3	81.8	80.1	79.4	80.4	73.3
	L5	75.1	75.8	73.1	73.5	69.5	75.3	74.4	75.7	70.7	68.0	76.4	76.3	75.4	75.3	67.9
	L10	72.8	73.9	71.2	71.2	66.1	71.3	72.3	73.1	68.9	64.7	74.1	74.2	73.3	73.2	64.3
	L50	67.9	68.7	66.3	64.2	50.8	65.5	67.3	67.0	61.3	49.6	68.9	68.6	68.1	65.7	50.5
	L90	62.9	64.0	61.5	55.1	43.7	60.5	63.4	61.2	53.5	42.6	63.9	64.7	62.0	57.7	45.7
	L95	61.5	62.8	60.4	52.9	42.7	59.1	62.2	59.5	52.1	41.8	62.1	63.5	60.1	56.2	45.4
	L99	59.0	61.1	58.7	49.6	41.0	56.9	59.9	56.9	48.9	41.1	59.3	61.6	57.2	53.8	45.1
	Leq	**70.4**	**71.1**	**68.5**	**68.6**	**62.6**	**69.8**	**69.7**	**70.6**	**65.8**	**63.1**	**71.6**	**71.2**	**70.5**	**69.8**	**61.5**
Exceeding the lim. level [dB(A)]		**5.4**	**6.1**	**3.5**	**13.6**	**7.6**	**4.8**	**4.7**	**5.6**	**10.8**	**8.1**	**6.6**	**6.2**	**5.5**	**14.8**	**6.5**
Rating noise level [dB(A)]		**70**			**67**		**70**			**65**		**71**			**67**	
Exceeding the lim. level [dB(A)]		**5**			**12**		**5**			**10**		**6**			**12**	

4. THE ANALYSIS OF RESEARCH RESULTS

Based on the results of the noise monitoring on the territory of the city of Niš, this paper pays special attention to analysing the change in the noise parameters at three characteristic measurement spots during the previous three years (2009÷2011). The selected measurement spots are located in the vicinity of the main traffic artery going through the city centre and along which we find areas serving different purposes and having various contents. The characteristic which the three selected spots have in common is the intensity of traffic during the entire day, traffic being the main source of noise at these locations.

4.1 The analysis of the noise monitoring at the measurement spot 1

Dr Zorana Đinđića Boulevard is one of the busiest streets in the city of Niš, which means that the noise level in its vicinity is determined by the structure and the dynamics of road traffic. By comparing the results obtained at the measurement spot 1 in the previous three years and weighing them against the allowed values of the noise level at the given location, we can conclude the following:

- The equivalent noise level in the day and night measurement periods shows a trend of permanent growth year after year (figures 1 and 2);
- The equivalent noise level in the day and night measurement periods went beyond the allowed level of noise of 50 dB(A) for the day measurement interval and 40 dB(A) for the night measurement interval, these limits being determined by the national regulation of areal contents and purposes (figures 1 and 2);

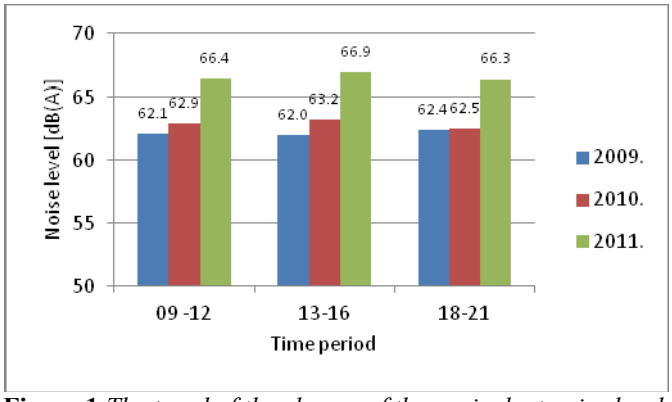


Figure 1 *The trend of the change of the equivalent noise level in the day measurement periods at the measurement spot 1*

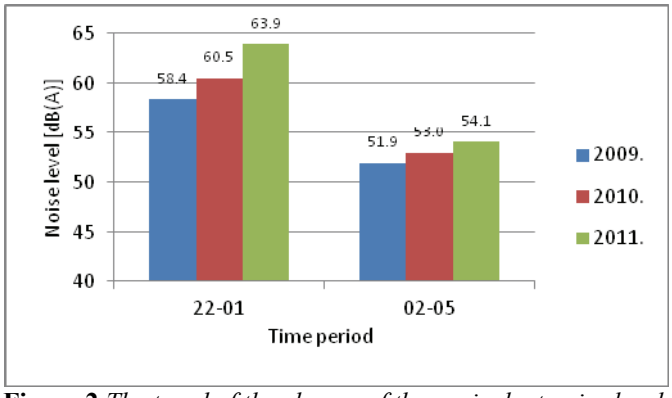


Figure 2 *The trend of the change of the equivalent noise level in the night measurement periods at the measurement spot 1*

- During all three years, the rating noise level for the day and the night measurement intervals went beyond the limit of the allowed noise levels at the given location (figures 3 and 4);
- The exceedings the limited noise levels were particularly noticeable during the night period and they got increased over time (figures 3 and 4);

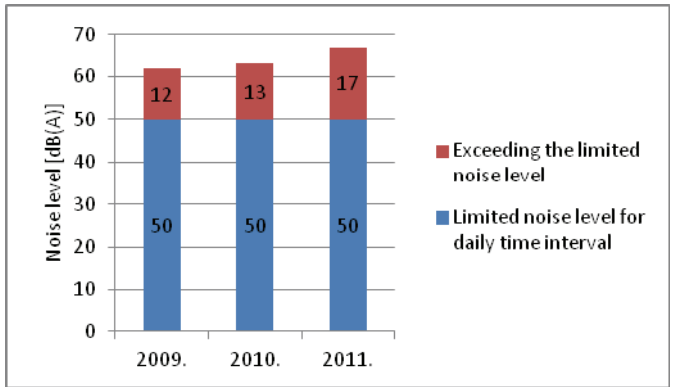


Figure 3 *The trend of the change of the rating noise levels in the day measurement interval with exceedings the limited noise level at the measurement spot 1*

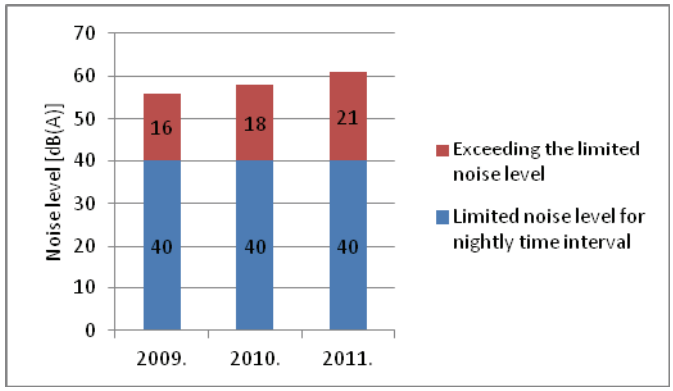


Figure 4 *The trend of the change of the rating noise levels in the night measurement interval with exceedings the limited noise level at the measurement spot 1*

- The structure and dynamics of road traffic had a dominant impact on the noise level at the given location;
- The structure of the traffic in dr Zorana Đinđića Boulevard predominantly involved cars (figures 5 and 6);
- A relatively small percentage of bus traffic significantly contributed to the general noise level at this location.

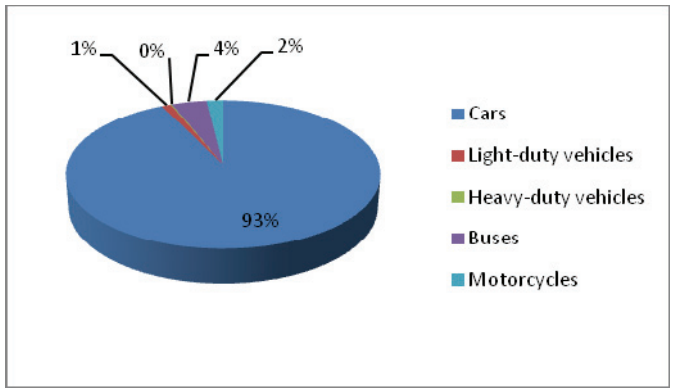


Figure 5 *Vehicle structure in the day measurement interval at the measurement spot 1*

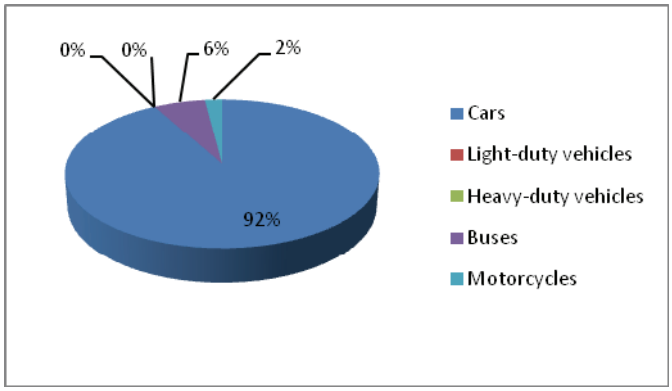


Figure 6 *Vehicle structure in the night measurement interval at the measurement spot 1*

4.2 The analysis of the noise monitoring at the measurement spot 2

Vožda Karađorđa Street is an extension of dr Zorana Đinđića Boulevard. Similarly, it is a very busy road, which means that the noise level in the vicinity of the road is mostly determined by the structure and dynamics of the road traffic.

By comparing the results obtained at the measurement spot 2 in the previous three years and weighing them against the allowed values of the noise level at the given location, we can conclude the following:

- The equivalent noise level in the day measurement periods shows a trend of permanent in the previous two years (figure 7);
- The equivalent noise level in the night measurement period between 10:00 and 01:00 was chiefly constant, and its value varied in the period between 02:00 and 05:00 year by year, with no clear change patterns (figure 8);
- The equivalent noise level in the day and night measurement periods went beyond the allowed level of noise of 50 dB(A) for the day measurement interval and 45 dB(A) for the night measurement interval, these limits being determined by the national regulation of areal contents and purposes (figures 7 and 8);

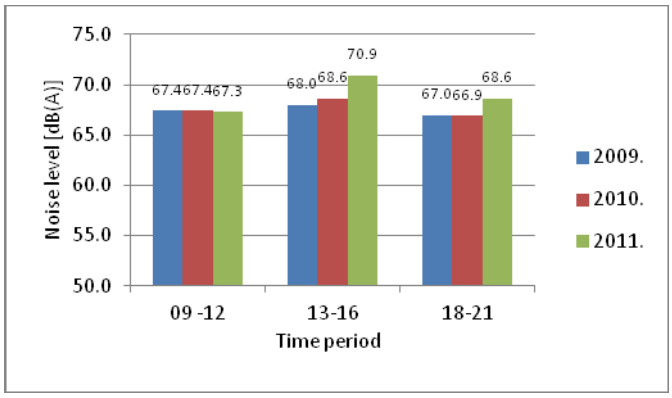


Figure 7 *The trend of the change of the equivalent noise level in the day measurement periods at the measurement spot 2*

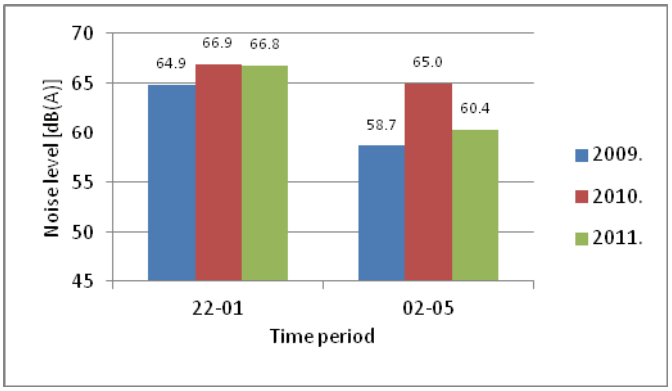


Figure 8 *The trend of the change of the equivalent noise level in the night measurement periods at the measurement spot 2*

- During all three years, the rating noise level for the day and the night measurement intervals went beyond the limit of the allowed noise levels at the given location (figures 9 and 10);
- Exceedings the limited noise levels are very high during both time intervals and are becoming more and more over time (figures 9 and 10).

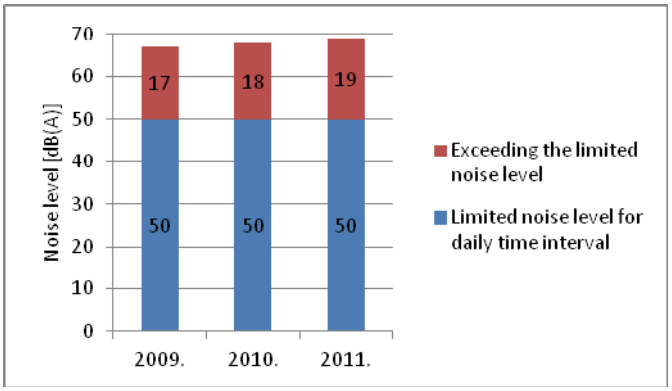


Figure 9 *The trend of the change of the rating noise levels in the day measurement interval with exceeding the limited noise level at the measurement spot 2*

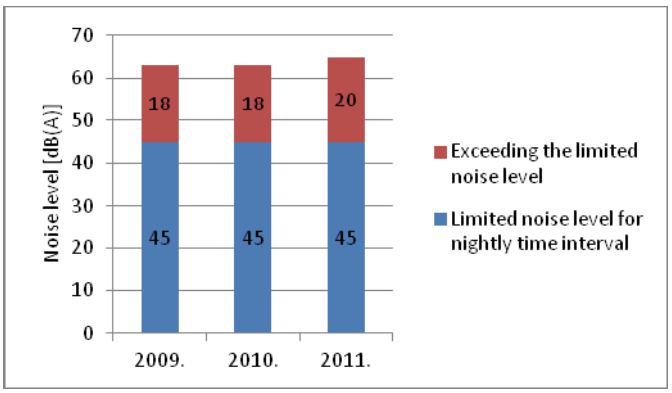


Figure 10 *The trend of the change of the rating noise levels in the night measurement interval with exceeding the limited noise level at the measurement spot 2*

- The structure and dynamics of road traffic had a dominant impact on the noise level at the given location;
- The structure of the traffic in Vožda Karađorđa Street predominantly involved cars (figures 11 and 12);
- A relatively small percentage of bus traffic significantly contributed to the general noise level at this location.

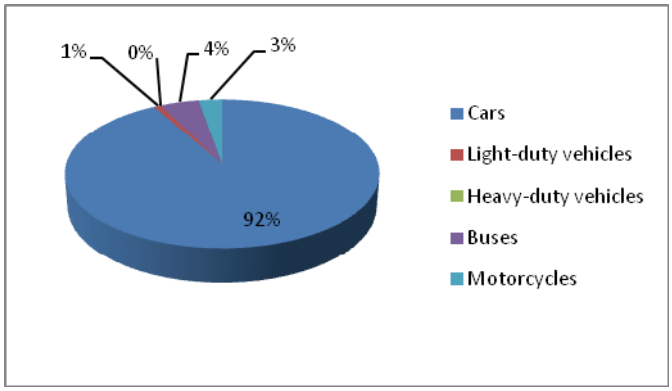


Figure 11 *Vehicle structure in the day measurement interval at the measurement spot 2*

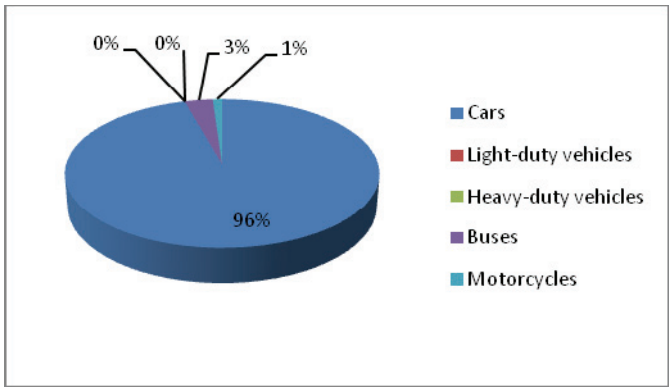


Figure 12 *Vehicle structure in the night measurement interval at the measurement spot 2*

4.3 The analysis of the noise monitoring at the measurement spot 3

Kralja Milana Square represents the very centre of the city of Niš. It is characterized by very intense communal activities, which are the consequence of the traffic in Vožda Karađorđa Street and Generala Milojka Lešjanina Street, of the structure and the activity of pedestrians in the pedestrian zone in Milana Obrenovića Street, as well as other activities characteristic of the city core.

The noise level in the vicinity of the road is mostly determined by the structure and dynamics of the road traffic.

By comparing the results obtained at the measurement spot 3 in the previous three years and weighing them against the allowed values of the noise level at the given location, we can conclude the following:

- The equivalent noise level in the day and night measurement periods shows a trend of permanent growth year after year (figures 13 and 14);
- The equivalent noise level in the day and night measurement periods went beyond the allowed level of noise of 65 dB(A) for the day measurement interval and 55 dB(A) for the night measurement interval, these limits being determined by the national regulation of areal contents and purposes (figures 13 and 14);

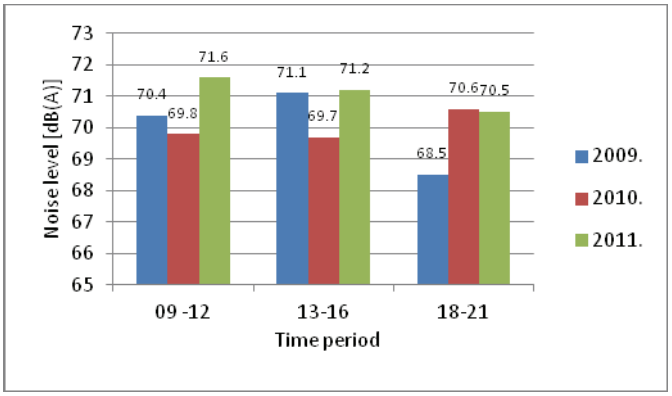


Figure 13 *The trend of the change of the equivalent noise level in the day measurement periods at the measurement spot 3*

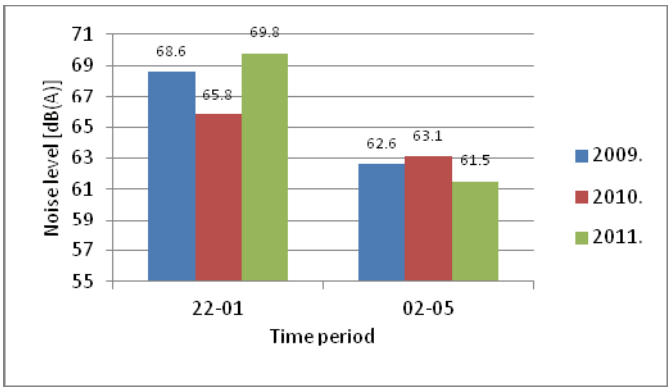


Figure 14 *The trend of the change of the equivalent noise level in the night measurement periods at the measurement spot 3*

- During all three years, the rating noise level for the day and the night measurement intervals went beyond the limit of the allowed noise levels at the given location (figures 15 and 16);
- The extent of exceeding the limited noise levels varied to a small degree year by year – the rating noise level at the given location was mostly constant. The exceedings the limited noise levels were particularly noticeable during the night period (figures 15 and 16).

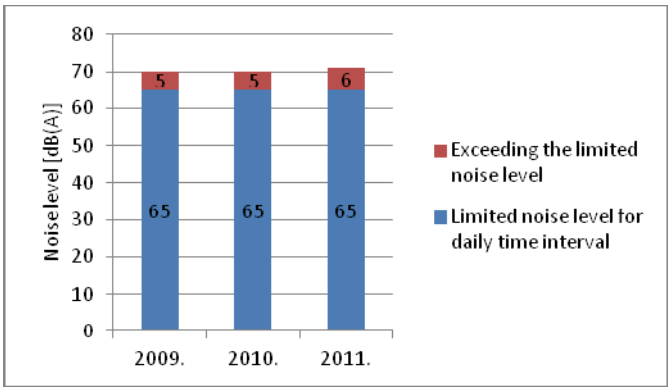


Figure 15 *The trend of the change of the rating noise levels in the day measurement interval with exceeding the limited noise level at the measurement spot 3*

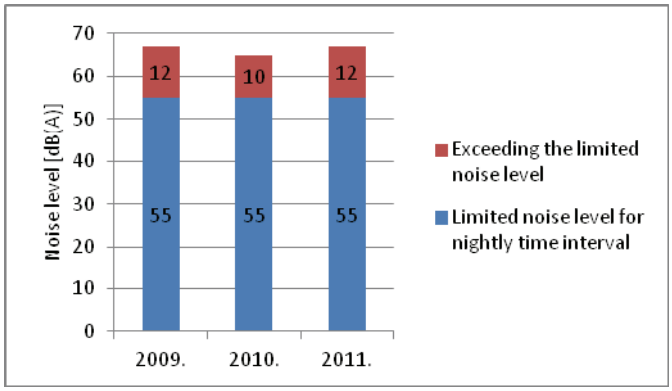


Figure 16 *The trend of the change of the rating noise levels in the night measurement interval with exceeding the limited noise level at the measurement spot 3*

- The structure and dynamics of road traffic had a dominant impact on the noise level at the given location;
- The structure of the traffic in Kralja Milana Square predominantly involved cars (figures 17 and 18);
- A relatively small percentage of bus traffic significantly contributed to the general noise level at this location.

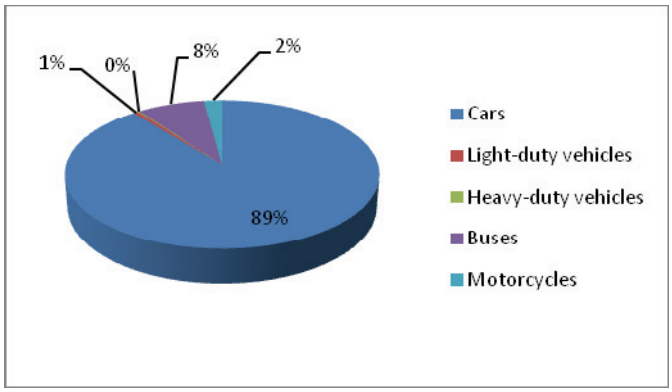


Figure 17 *Vehicle structure in the day measurement interval at the measurement spot 3*

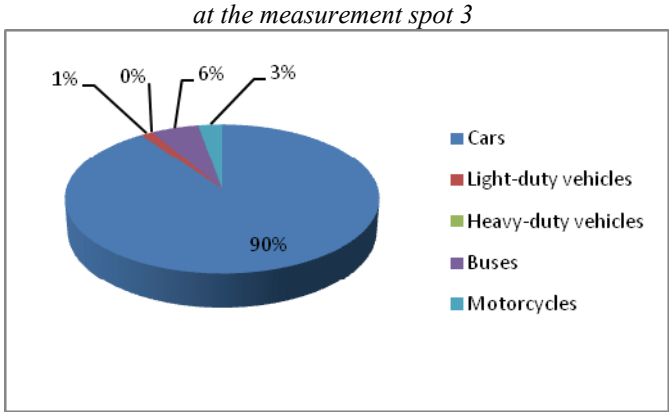


Figure 18 *Vehicle structure in the night measurement interval at the measurement spot 3*

4.4 A general analysis of the level of noise on the territory of the city of Niš

On the basis of the noise level monitoring results for the years 2009, 2010 and 2011, it is possible to create an overview of the noise levels on the territory of the city of Niš in the previous period. An essential piece of information in the process of evaluating noise pollution is the yearly percentage of the measurement spots (44 of them) with the associated referential level values – table 5, followed by the yearly percentage of the measurement spots with the intervals of the exceedings the limited noise levels for specific measurement intervals in accordance with the areal contents and purposes (SRPS U.J6.205) – table 6.

Table 5 *The yearly percentage of the measurement spots with the values of the rating noise levels within the specific range*

Rating noise level [dB(A)]	2009.		2010.		2011.	
	day	night	day	night	day	night
40÷45	0.00	2.27	0.00	2.27	0.00	2.27
46÷50	2.27	9.09	2.27	6.82	0.00	0.00
51÷55	2.27	15.91	2.27	15.91	2.27	6.82
56÷60	20.45	38.64	20.45	45.45	4.55	27.27
61÷65	34.09	29.55	38.64	29.55	22.73	52.27
66÷70	38.64	4.55	34.05	0.00	59.09	11.36
>70	2.27	0.00	2.27	0.00	11.36	0.00

Table 6 *The yearly percentage of the measurement spots with the intervals of the exceeding the limited noise level for the day and night measurement intervals*

Exceeding the limited noise level [dB(A)]	2009.		2010.		2011.	
	day	night	day	night	day	night
no exceedance	41.00	7.00	41.00	7.00	41.00	7.00
1÷5	43.18	40.91	38.64	59.09	52.27	25.00
6÷10	9.09	38.64	9.09	34.09	18.18	47.73
11÷15	0.00	6.82	0.00	2.27	6.82	15.91
>15	2.27	2.27	2.27	2.27	4.55	9.09

5. CONCLUSION

The analysis of the noise monitoring on the territory of the city of Niš for the previous 3-year period (2009, 2010 and 2011) leads us towards the following conclusions:

1. Motor vehicle traffic largely influenced the noise levels at the examined locations;
2. The share of cars in the structure of vehicle was as large as 90%. A small percentage of buses which took part in the traffic had a strong impact on the noise levels at the examined locations;
3. The exceeding the limited noise levels were the gravest during the night measurement interval; One of the main reasons for this was the higher overall speed due to the lower traffic intensity;
4. The extent of the exceeding the limited noise levels at the examined locations had a tendency of growing with time – the rating noise levels were getting higher every year, which means that the exceeding the limited noise levels got bigger as well;
5. It is necessary to take serious provisions to cope with the problem of noise pollution at all locations which are proven to be endangered, first of all by preparing the required documentation and later on by urging the authorities to implement the concrete solutions.

ACKNOWLEDGEMENT

This research is part of the project "Development of methodology and means for noise protection from urban areas" (No. TR-037020) and "Improvement of the monitoring system and the assessment of a long-term population exposure to pollutant substances in the environment using neural networks" (No. III-43014. The authors gratefully acknowledge the financial support of the Serbian Ministry for Education, Science and Technological Development for this work.

REFERENCES

[1] Barboza, M. J., Carpenter, S. P. and Roche, L. E.: "Prediction of traffic noise: A screening technique", *Journal of Air and Waste Management Association* 45, pp. 703–708, 1995.

[2] Bies, D. A., Hansen, C. H.: "Engineering Noise Control: Theory and Practice", 2nd ed., E and FN SPON, London, 1996.

[3] Davis, M. L., Masten, S. J.: "Principles of Environmental Engineering and Science", McGraw-Hill, 2004.

[4] European Environment Agency (EEA), "Environment in the European Union at the turn of the century", Copenhagen, Denmark: European Environment Agency, 1999.

[5] Georgiadou, E., Kourtidis, K. and Ziomas, I.: "Exploratory traffic noise measurements at five main streets of Thessaloniki, Greece", *Global Nest I International Journal* 6(1), pp. 53–61, 2004.

[6] Jamrah, A., Al-Omari, A. Sharabi R.: "Evaluation of traffic noise pollution in Amman, Jordan", *Environmental Monitoring and Assessment* (2006) 120: pp. 499–525, Springer, 2006.

[7] Langdon, F. J. and Griffiths, I. D.: "Subjective effects of traffic noise exposure", *Journal of Sound and Vibration*, 1981.

[8] Maschke, C. P.: "Preventive medical limits for chronic traffic noise exposure", *Acoustica* 85, pp. 448, 1999.

[9] Mihajlov, D., Praščević, M., Cvetković, D.: "Results of the monitoring and assessment of the state of noise level in Niš in 2007", *21st Conference with international participation "Noise and Vibration"*, Tara, Serbia, 2008.

[10] Praščević, M., Cvetković, D.: "Environmental noise", 1st edition, Faculty of Occupational Safety of Niš University, Niš, Serbia, 2005.

[11] Skanberg, A. and Ohrstrom, E.: "Adverse health effects in relation to urban residential soundscapes", *Journal of Sound and Vibration* 250(1), pp. 151–155, 2002.

[12] Stanners, D., Bourdeau, P.: "Europe's environment - the Dobris assessment", European Environment Agency, 1995.

[13] Stoilova, K., Stoilov, T.: "Traffic noise and traffic light control", *Transportation Research, Part D: Transport and Environment*, 3(6), pp. 399-417, 1998.

[14] Theebe, M. A.: "Planes, trains, and automobiles: The impact of traffic noise on house prices", *The Journal of Real Estate Finance and Economics* 28(2-3), pp. 209–234, 2004.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

ANALYSIS OF SYSTEMATIC MEASUREMENTS OF NOISE IN CITIES

Marina Pljakić, Branko Radičević, Jelena Tomić, Zvonko Petrović

Faculty of Mechanical Engineering Kraljevo, University of Kragujevac, Serbia, pljakic.m@mfkv.rs

Abstract - *This paper presents an analysis of the reports on systematic measurements of noise in several Serbian cities. The analysis considered the contents of the report, type and number of data which are presented in the reports (noise level, the description of measurement, measurement conditions, etc.). The analysis was made from the point of application of standards SRPS ISO 1996-1:2010 and SRPS ISO 1996-2:2010. Chart review indicates which data are presented in individual reports. In order to provide unification of measurements and presentation of the results, a minimum content of the report is proposed. The analysis includes a critical review of the possibilities of application of the obtained data for implementation of control points in noise maps. Besides, in the paper are shown the activities which were carried out by local governments on basis of the reports.*

1. INTRODUCTION

The sound is part of our daily lives, but it can often be uncomfortable or unwelcome, thus representing noise. Environmental noise - communal noise is unwanted or harmful sound external environment created by human activity. The main source of noise pollution is traffic. Engine operation, the sound of sirens, squeaking brakes, work of technically defective vehicles and, in particular, restarting a vehicle after stopping at a traffic light (at the same time when moving large numbers of vehicles) are effects which increase the noise level. There are many sources of noise at different frequencies, so it is difficult to identify individual contributions to the overall noise level. Besides traffic, as the most important source of noise in the streets, there are other sources of noise, such as the frequent strong closing of vehicle doors, people buzz on the street, barking dogs, noise from independent workshops and restaurants, music from the sound system, as well as many other phenomena that increase noise and which are present on the streets of cities.

As opposed to the industrial noise, which primarily damages the hearing, communal noise primarily affects quality of life, disrupting the natural rhythm of work and rest. The most common causes are uneasiness, tension and lack of concentration.

There is a large number of regulations governing the measurement of environmental noise: the Law on the Protection of the noise in the environment, the regulation of noise indicators, limits, methods for evaluating indicators of noise, disturbance and adverse effects of environmental noise, rules of the methodology for determining acoustic zone, regulations on methods of measuring noise, the content and scope of the report on the measurement noise, the ordinance on the conditions to be met by a professional organization to measure noise, as well as the documentation submitted with the request for authorization for noise measurement, acoustic zoning, Standards SRPS ISO 1996-1:2010 and SRPS ISO 1996-2:2010.

In addition to these regulations, the relevant institutions in each city make additional decisions on protective measures against noise and systematic measurement of acoustic noise in the established areas of the city.

Analysis of the results of systematic noise measurements in cities shown that the main parameters and process of the noise measurements are applied according to the appropriate standards.

2. THE METHODOLOGY FOR MEASURING

Measurement of noise in cities was performed on a varying number of measurement locations and in varzing times of the day and night. Number of measuring locations ranges from 3 to 40 and are differently defined areas in which noise is measured. According to the standard, defined by the six acoustic zone as follows:

- areas for recreation, hospital and rehabilitation zones, cultural and historical sites, great parks;
- tourist areas and small villages, camps and school zones;
- purely residential areas;
- business and residential areas, commercial and residential areas and playgrounds;
- city center, craft, trade, administrative zone with flats, along area highways, highways and city roads;
- industrial, warehouse and service areas and transportation terminals without residential buildings.

For each measuring point, in addition to noise level data, the reports include information on the conditions of measurement, description of location where the device was set to measure, traffic frequency, and graphic attachments.

In Table 1 is shown which of the basic data should be included in a report on noise measurement according to the SRPS ISO 1996-2:2010, and to what extent these data are represented in the reports for cities in Serbia.

Table 1. *Information listed in the report on the measurement of noise in cities*

Measurement information that is must be recorded and noted in the report \ Cities which are included in the analysis	Novi Sad	Zrenjanin	Vršac	Pančevo	Inđija	Užice	Kragijevac	Niš	Kraljevo	Beograd
The time, date and place of measurement	•	•	•	•	•	•	•	•	•	•
Instruments and their calibration	•	•	•	•	•	•	•	•	•	•
Measured and, if relevant, corrected sound pressure levels (L_{eqT}, L_E, L_{max}), A-weighted (and optional C-weighted), and optionally, in the frequency bands	•	•	•	•	•	•	•	•	•	•
Measured levels of N percentage ($L_{N,T}$) including the accrual (sampling rate and other parameters)	•	•				•		•	•	
Evaluation of uncertainty of measurement together with the probability of coverage		•								
Information on sound pressure levels during the measurement of residual volume	•	•				•	•	•	•	
Time interval measurements	•	•	•	•	•	•	•	•	•	•
Description of working conditions, including the number of passes of cars / trains / planes listed for each respective category	•	•			•	•	•	•	•	•
Description of meteorological conditions, including wind speed, wind direction, cloudiness, temperature, barometric pressure, humidity, precipitation, and the presence and location of sensors for wind and temperature	•	•			•	•	•	•	•	
The methods used for the exploitation of the measured values for other conditions										

3. DATA ANALYSIS AND RESULTS OF THE NOISE MEASUREMENTS

Measurement interval in all cities is 15 minutes, while the number of measurements during the day and night varies. Some cities in the reports of a systematic measurement noise have data on two measurements during a day (6-18h), one during the evening (18-22h) and two during the night (22-6h), while some reports have data about a day and night measurements noise.

Numeric values that are shown in the reports are:

- the value of daily noise indicators (L_{day}) in the environment;
- the value of the indicator evening noise ($L_{evening}$) in the environment;
- the value of the indicator nighttime noise (L_{night}) in the environment;
- the value of the total noise indicators (L_{den}) in the environment;
- percentage of the population endangered by noise (A%) of road traffic during the day and during the night and the percentage of the population highly vulnerable to noise (NA%) (comparing to the determined value of L_{den} at measuring points) - Novi Sad;
- the recorded values of the equivalent noise level (L_{Aeq});
- the permissible noise level;
- average noise level (day, evening, night) – Kraljevo;
- the established value of the frequency for a fixed maximum equivalent noise level - Novi Sad.

Number of measurements on a monthly and annual basis also varies. In Novi Sad and Zrenjanin noise measurements are performed each month at all measuring points, while in Nis, Kraljevo, Kragujevac, Užice and Belgrade are made in spring or autumn measurements.

The analysis revealed the following:

- there are consecutive terms of measurement noise, which is not desirable;
- the data for the measurement of spring and autumn in some cities are identical, which raises concern about their credibilty;
- measured data for some measurement points in different occassions coincide completely, which also raises credibilty concerns;
- institutions that deal with measurement of noise usually publish partial or complete reports on their

websites or on the official website of the city government;

- it is not possible to look at recent reports on the noise measurement, because the data are not updated regularly;
- measures to be taken regarding noise protection are not clearly defined in the report on systematic measurements of noise in cities.

In Table 2 are shown the numbers of noise measurements on a monthly and annual basis in the cities that were included in the analysis, and Table 3 shows basic data measurement noise in Kraljevo for one measuring point where traffic has a dominant effect on the noise.

Table 2. *Number of measurements during the months and year*

Cities	Novi Sad	Zrenjanin	Vršac	Pančevo	Inđija	Užice	Kragujevac	Niš	Kraljevo	Beograd
Number of measuring points	9	20	6	8	3	22	6	11	40	35
Monthly measurements	45	100	12	16	15	110	30	55	200	70
Annual measurement	540	1200	24	16	15	110	60	55	200	140

Table 3. *The measured values of key indicators of noise in Kraljevo*

No.	Time	Date	L_{Aeq} [dBA]	L_{AF95} [dBA]	L_{AF50} [dBA]	L_{AFmin} [dBA]	L_{AFmax} [dBA]	Number of vehicles	
								„light“	„heavy“
1.	08.56-09.11	28.07.2011	61.6	50	57	51.3	77.7	267	15
2.	20.05-20.20	27.07.2011	62.1	45.5	53	47.7	72.5	165	8
3.	00.11-00.26	27.07.2011	56.3	34.5	43	35.1	71.7	56	0
Cumulative noise: 67.2 dBA									

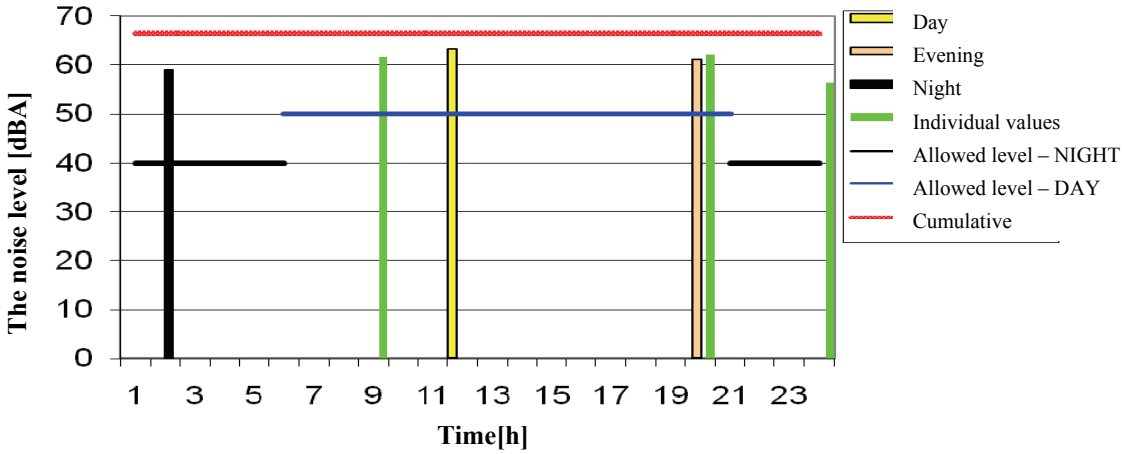


Fig. 1. *Graphic display of measurement results of noise*

Figure 1 provides a graphical representation of the results of the noise measurements whose values are given in Table 3.

To measure the equivalent noise level were used sound level meters, of various types such as, Bruel & Kjaer Observer, 2260, 2250 or 2238-G type, class 1, With these instruments it is possible to do all the measurements and analysis on the assessment of noise pollution, and noise in the workplace. The instruments also meet all the required IEC (61672 standard) and ANSI standards.

The results are shown in decibels (dB), based on measurements of the equivalent noise level (L_{Aeq}).

4. STRATEGIC NOISE MAPS, „NOISE MAPPING“

For strategic noise mapping is used so-called basic indicators of noise. These are: the daily noise indicator (L_{day}), evening-noise indicator ($L_{evening}$), night noise indicator (L_{night}) and an indicator that describes the noise annoyance over 24 hours L_{den} (day-evening-night). These are longer, weighted average sound level for all of these periods in a year.

Strategic noise maps are data on the current and estimated noise levels, which are shown by noise indicators. The maps contain detailed information on the state of environmental

noise; (excess of the prescribed limits, estimating the number of people, households, schools and hospitals that are exposed to noise above the prescribed limit. Strategic noise maps for agglomerations in the territory of the local government makes local governments (Law on the Protection of the noise in the environment). Systematic measurement noise in cities should serve as a control point map noise.

Carrying out the day and night noise measurement would be impossible - because it is too time-consuming and expensive. Therefore, calculations based on a reliable methodology are being used. Digital terrain model, structural features of buildings, the number of people on one side and the road network, traffic volume, fences, existing speed limits on the other hand are used in making these calculations.

The above measurements of noise pollution and the geographic distribution of the noise emission are presented for an area by colors, where the colors represented different intervals sound level, in order o identify the problematic points in the urban environment where the noise level is higher than the norm.

This is the basis for planning processes and actions to reduce noise levels, and for planning and construction. Necessary steps would be collecting data on traffic and industry, the introduction of digital models that include buildings, boundaries, topography of the terrain and calculate the (future) of likely noise levels using appropriate software and noise propagation model. Proposal of basic data which should contain statements about the measurement noise are given in Appendix 1

5. CONCLUSION

A large number of cities, which perform systematic measurement of noise, did not respond to our request to send us their reports, at least in part. Therefore, we were not able to make detailed comparisons of the measurement noise in all towns in Serbia.

The control system of traffic in cities has not changed enough to prevent excessive noise: setting up barriers between residential buildings, schools and main traffic roads is still in the conceptual stage. In Kraljevo, are made projects with sound barriers for school „Dimitrije Tucović" and settlements near a major overpass. Currently these projects are awaiting funding necessary for realizatione. It is also necessary to determine appropriate funding institutions that deal with the noise impact on the environment (in Kraljevo's Local Environmental Action Plan-LEAP). Respective authorities should be starting solving the problem of noise in cities because reports show that the noise in many cases above the permitted level.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to Serbian Ministry of Education and Science for support through project TR37020.

REFERENCES

[1] Momir R. Praščević, Dragan S. Cvetković: „Enviromental noise", University of Nis, Faculty of Occupational Safety, First Edition 2005., ISBN: 86-8026-53-X

[2] Dragan S. Cvetković, Momir R. Praščević: „Noise and vibration", University of Nis, Faculty of Occupational Safety, First Edition 2005., ISBN: 86-80261-45-9

[3] Standards SRPS ISO 1996-1:2010 i SRPS ISO 1996-2:2010

[4] Reports of systematic measurement noise for cities: Kraljevo, Užice, Niš, Zrenjanin, Novi Sad, Beograd, Kragujevac, Vršac, Inđija, Pančevo

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

CALIBRATION OF SOUND LEVEL METER

Mirjana Mladenović

Technical Test Center, Belgrade, metrologija@toc.vs.rs

Abstract – *This article reports about sound level meters calibration requirements and methods, according to International Standard IEC 61672-3, Electroacoustics-Sound level meters Part 3: Periodic tests.*

1. INTRODUCTION

Sound level meter (phonometer - SLM) is the precise device for measuring sound level. It consists of electronics which tranduce sound pressure from condenser microphone to electrical signal on the display. Some of them have software for analyze and storage of measured sound pressure level values.

According to International Organization Of Legal Metrology (OIML), all instruments which is used in protection and safety of the public should be verified.

Standard IEC 61672 - Parts 1 [1] define full specification for all sound level meters. IEC 61672 - Parts 2, define pattern evaluation tests and IEC 61672-Parts 3 [2], define limited set of tests required to verify phonometer. Phonometer class 1 with higher accuracy is used in laboratory but SLM class 2 with lower accuracy is for field used.

According to method of measure there are three models of sound level meters:

- **Conventional sound level meter** that measures exponential time-weighted sound level (as logarithmic square root ratio of measured and reference level of sound pressure);
- **Integrated-averaging sound level meter that measures time-average sound-level** (logarithmic square root ratio of measured and reference level of sound pressure, in a certain period of time);
- **Integrating sound level meter** that measures sound exposure level (integral of square root of measured sound pressure level in certain period of time).

Phonometers can measure sound pressure level with frequency weighting A, C and Z, and time weighting FAST (F) и SLOW (S)– which is performed in manufacture specification.

2. CALIBRATION METHOD

SLM calibration method consists of acoustic and electrical tests. Acoustic tests are required for single frequency weighting but electrical tests are required for checking the characteristics of different frequency weightings available in the SLMs.

Acoustic test, figure 1, is performed by indication of sound pressure level when the acoustic calibrator and condenser microphone are connected to the phonometer.

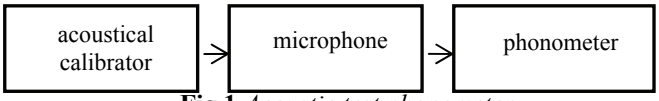


Fig 1 *Acoustic test phonometer*

Electrical tests is performed, figure 2, when the input electrical signal of specific level and frequency, is inserted on the phonometer.

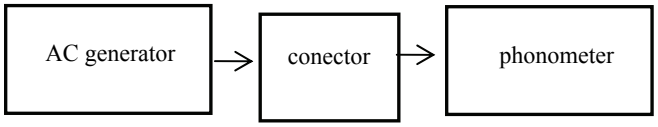


Fig 2 *Electrical test phonometer*

In practice, before and after every acoustic measurement functional phonometer checking is performed, on one frequency, using acoustic calibrator. Certainly it is not replacement for periodical testing.

For regular work of phonometer it is necessary before and after measurement to check battery power according to manufacturer's specification.

Environmental conditions in the laboratory is controlled in the (23 ± 0,5)°C and (50 ± 15) % RV. Ambient atmospheric pressure should be between 100 kPa and 103 kPa.

3. METHOD AND MEASUREMENTS RESULTS

In this paper is given an example of class 1 phonometer calibration, B&K 2250, according to the metrology characteristics, given in table 1.

3.1 Indication at the calibration check frequency

This test checks the indication of the display of the SLM at a single frequency and level by sound calibrator. SLM is checked with microphone fitted on it and exposed to sound pressure level with the sound calibrator. Values of sound pressure level are compared on output of acoustic calibrator and those which are presented on the display of phonometer, table 2.

Table 2 *Results of reference level indication*

BK 4231 (f =1000Hz):	SPL = 94, 1 dB
	SPL_{mv} = 94,2 dB

3.2 Indication of the electrical output

Electrical test of output confirmes that the indication from the electrical output and the corresponding indications on SLM display are identical within the allowable tolerances (according to IEC61672-1), table 3.

Table 3 *AC voltage*

U_{vi} (dB)	0	-10	-20	-30	-40	-50
SPL (dB)	120	110	100	90	80	70
SPL_{mv} (dB)	120	110	99,9	89,9	80,0	69,9

3.3 Self generated noise

Acoustic noise level checking is performed by measuring sound pressure level, for A-weighting function, with the microphone installed, at the most sensitive level range in anechoic room.

Electric test of self generated noise is measured by replacing microphones with appropriate electrical input signal devices which is short-ended and averaging ten sound pressure levels with time-weighting S over a 60 s. If measured level of noise exceeds error margin (IEC 61672-1) it doesn't mean that characteristic of phonometer is unacceptable. Results are given for all weighted filter functions and for time weighting function of 60s without allowed errors, table 4.

Table 4 *Results of noise level*

$SPL_{mv\check{s}um}$ = 11,9 dB(A)
$SPL_{mv\check{s}um}$ = 12,4 dB(C)
$SPL_{mv\check{s}um}$ = 10,9 dB(Z)

3.4 Frequency characteristic

Frequency characteristic is determined at nominal octave intervals from 63 Hz to 16 kHz (in this case 4 kHz). Sinusoidal electrical signal at frequency 1kHz is inserted through input, with amplitude sufficient to give an indication 45 dB below the upper linear limit on display of phonometer By changing the frequency of electrical signal, simultaneously signal amplitude is changing in the manner so that compensates attenuation towards IEC 61672-1 for the relevant frequency weightings, table 5.

Table 5 *Results of frequency characteristic*

f(Hz)	SPL_{mv} dB(A)	SPL_{mv} dB(C)	SPL_{mv} dB(Z)	G_{dozv} (dB)
63	48,7	74,2	75,0	± **1,5**
125	58,8	74,8	75,0	± **1,5**
250	66,3	75,0	75,0	± **1,4**
500	71,6	75,0	75,0	± **1,4**
1000	75,0	75,0	75,0	± **1,1**
2000	76,5	74,7	75,0	± **1,6**
4000	75,8	74,0	75,0	± **1,6**

3.5 Time and frequency weightings

Performance of the A, C and Z (Lin) weighting and time weightings F and S is done with sinusoidal electrical signal at frequency of 1kHz and amplitude which adjusted to give an indication of 94 dB(A) on display of phonometer. Levels of sound signal for different time and frequency weighting functions (FAST, SLOW) and (A, C, Z) are recorded, table 6.

Table 6 *Results of weighting function*

"F"; G_{dozv} = ± 0,4 dB			"S"; G_{dozv} = ± 0,3 dB	
SPL dB(A)	SPL dB(Z)	SPL dB(C)	SPL dB(A)	SPL dB(L_{Aeq})
94,0	94,0	94,0	94,0	94,7

3.6 Level linearity on reference level range

Level linearity of the display on referent range, is measured by using steady sinusoidal electrical signal, at frequency of 8 kHz which determines level in (dBA) and for S time weighting. The amplitude of the signal set to give an indication at the reference level of 94 dB.

The signal is then increased in 5 dB steps up to within 5 dB of the upper limit of the linear operating range. After that the signal is increased in 1 dB steps until overload, not including first indication. In the same way amplitude of its decreasing which causes level change from 5 dB towards lower specified limit. Then electric signal amplitude is decreased in 1 dB steps down to, but not including the first indication of under-range indication, table 7.

Table 7 *Results of linearity on referent range*

For one referent range		
SPL dB(A)	SPL_{mv} dB(A)	G_{dozv} (dB)
121,0	120,9	± **1,1**
120,0	119,9	
119,0	119,0	
114,0	114,0	
109,0	109,0	
104,0	104,0	
99,0	99,0	
94,0	94,0	
89,0	88,9	
84,0	83,7	
79,0	78,9	
78,0	77,9	
77,0	76,8	
75,0	74,8	
73,0	73,0	
71,0	70,9	
70,0	70,0	

3.7 Overload indication

Overload indication checking is applicable for phonometers with time averaging sound level. Electric signal level, frequency f = 4 kHz, is set so that indication $L_{Aeq,}$ should be 1 dB below upper limit of phonometer linear range. From signal stands out positive and negative halfperiod signal. For positive halfperiod signal, overload is being recorded when signal level is increasing by 0,5 dB, and then by 0,1 dB. Same is done for negative halfperiod part of signal. When under overload, indicator lamp is lit, table 8.

Table 8 *Results of overload*

Positive half of cycle	SPL_{mv} dB(L_{Aeq})=125,0	Negative half of cycle	SPL_{mv} dB(L_{Aeq})=125,0

4. SUMMARY

IEC 61672-3 standard allows periodical examination, calibration of phonometers using measurement equipment of good quality, with suggested period of calibration on two years.

Many characteristics of a SLM such as its physical shape and the microphone's directivity response don't change with time and don't require periodic tests.

Calibration analysis of different phonometer models, suggests that some older models of phonometers can not satisfy all the standard IEC 61672-1,3 criteria.

This standard also doesn't include mechanical vibration examination. OIML R88 gives instruction for examining influence on vibrations, with sinusoidal signal which gives acceleration of 1 m/s^2 in the range from 20 Hz to 1 kHz.

Software checking, and phonometer calibration process in measurement chain with microphone preamplifier and microphone aren't processed in standard.
Measurement results can be compared with values of allowed limits if measurement uncertainty is taken into account. Measurement uncertainty analysis of phonometer calibration will be the topic of separate paper.

Table 1 *Metrology characteristics*

Number	Characteristics	Measurement range	Allowed error	Measurement uncertainty
Acoustic examination				
3.1	Indication at the calibration check frequency	124dB, 250Hz 94 dB, 1000Hz 114dB, 1000Hz	± 0,1 dB	± 0,17dB
Electric features				
3.2.	Indication of the electrical output	Δ20 dB	± 0,1 dB	± 0,06dB
3.3	Self generated noise			± 0,5dB
3.4.	Frequency characteristic on one sound pressure level, for weight filters: A, C, L(Z)	63 Hz до 16 kHz	±1,5 dB - ± 3,5 dB	± 0,1dB
3.5	Time and frequency weightings filter function at frequency of 1000 Hz	94 dB, 1000Hz	± 0,4dB	± 0,1dB
3.6	Level linearity on reference level range	20 dB до 140 dB Reference level 94 dB, 8 kHz	1,1 dB	± 0,1dB
3.7	Overload indication	4 kHz	± 1,8 dB	± 0,1dB

Metrological laboratory is accredited for phonometer calibration according to steps for which technical conditions are met.

In Technical Test Center, in laboratory for sound, response on short term electrical impulse and apical level for weight filter C is not possible to realize.

REFERENCES

[1] *International Standard CEI* IEC 61672-1:2002 *Electroacoustics – Sound level meters: Part 1: Specifications.*

[2] *International Standard* CEI IEC 61672-3:2002 *Electroacoustics-Sound level meters Part 3: Periodic tests*,

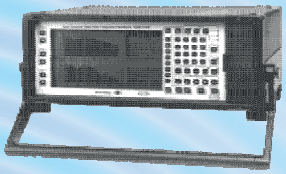
[3] "*Instructions for periodical sound level examination (phonometer)", Internal manual C.43.042, TOC*

CENTER OF TECHNICAL DIAGNOSTICS & NOISE AND VIBRATION LABORATORY

UNIVERSITY OF NIŠ
FACULTY OF OCCUPATIONAL SAFETY
Čarnojevića 10a, 18000 Niš
Tel.: 018 529-747; Fax: 018 529-748

Environmental noise & Occupational noise - measurement and analyis

- Rating noise level;
- Frequency analyis;
- Statistical analysis;



Human vibration

- Hand-arm vibration;
- Whole body vibration;



Sound power of noise sources

- Sound pressure method;
- Sound intensity method;





Room acoustics

- Time reverberation;
- Airborne sound reduction index
- Impact sound reduction index;

Urban noise

- Noise monitoring;
- Noise zoning;
- Strategic noise maps;





Predictive/preventive maintenace of machine

- Vibration condition monitoring;
- Vibrodiagnostics;
- Balancing of rotating machine;

Education

- Workshops;
- Courses;
- Long-term learning;





Design of noise and vibration control systems

- Design of noise insulation and absorption system;
- Design of vibration insulation and absorption system;
- Design of room acoustics;



University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

MANAGING INDUSTRIAL NOISE

Henk Wolfert[1]

[1] DCMR EPA, Centre for Environmental Expertise, The Netherlands, henk.wolfert@dcmr.nl

Abstract - *From 1996 DCMR EPA runs a management system on industrial noise called Information system Industrial noise or abbreviated I^2 (I square). One of the tasks of DCMR EPA is to manage industrial areas that are have been zoned in an acoustical way. I^2 makes it possible to manage the noise produced by industries situated in those areas. The system is based on an Oracle database combined with a user friendly interface. With the user interface it is possible to retrieve the stored information from the database. The database mainly contains acoustic, geographic and administrative data like acoustic power levels, coordinates of the sources, objects like barriers and receptors. System I^2 not only supports the process of keeping the limit values of those zones but it is also supportive in granting environmental permits to industry, monitoring, advises regarding spatial plans and it's the instrument to set up the industrial noise maps according to directive 2002/49 EU. Updating data takes place by putting in new data that is provided by acoustic assessments requested for issuing environmental permits. This process as well as the other processes mentioned before are formalised in quality control procedures. At the end of 2006 system I^2 has been modernised in an instrument that has more functions, based on new technology and linked to GIS.*

1. INTRODUCTION

This paper goes about management of acoustic industrial zone in the Rotterdam Metropolitan Area (hereafter abbreviated as RMA) and how zone management in this area is carried out. This paper is derived from a previous paper [1]. The Rotterdam Metropolitan Area is the region around Rotterdam and its harbour. Within the RMA 18 municipalities are situated. DCMR EPA noise department carries out the environmental tasks (noise prevention and abatement) for these 18 municipalities (including the city of Rotterdam) but also for the province of South Holland in this region. In this region about 1.2 million people are living and more than 20.000 enterprises are active, varying from a bakery or a butcher's till giant refineries, chemical industries and huge container terminals. DCMR EPA's noise department deals with noise caused by industry, road and rail traffic, airports, recreational activities, music, dance and sports events, building and construction works. She advises the local and provincial governments on spatial planning and other plans as well. She also is involved in issuing environmental permits by means of drafting the noise demands and inspection of these demands. More about our noise section can be found at DCMR's website [2]. From 1996 a noise management instrument is in operation at DCMR EPA, called Information system Industrial noise or I^2 (say I-square). One of the tasks of DCMR EPA is to manage zoned industrial areas as required by the Dutch Noise Abatement Act [3] which came into force in 1982. This Noise Abatement Act introduced noise zones along and around roads, industrial areas and railways. The industrial zone defines the amount of noise emitted by enterprises situated in the industrial areas. On the other hand these zones set strict criteria for building new houses and other sensitive objects such as hospitals, nursing homes, etc. within the zones area.

2. NOISE MANAGEMENT AND I^2

The system I^2 makes it possible to manage the noise produced by industries within in zoned areas. It means that limit values, established by the government, should be kept, now and in the future. It also means that when patches of ground are not occupied yet reservations should be considered in order to accommodate future industry at that zoned areas. The system I^2 is based on an Oracle database combined with a friendly user interface. With this user interface the stored information can be retrieved from the database. The database mainly contains acoustical, geographical and administrative data such as acoustic power levels, position of sources, screens, and receptors. System I^2 not only supports the process of controlling and safeguarding the limits of the zone but it also facilitates the process of granting environmental permits to industry, monitoring, advises and it is the providing instrument to set up the industrial noise maps according to Environmental Noise Directive 2002/49 EU (END). Updating data takes place by putting in new data that is provided by acoustic reports that are required during the process of issuing environmental permits, or advising spatial and/or housing plans. This process as well as the other processes mentioned before are formalised in quality control procedures. At the end of 2006 System I^2 has been modernised in an instrument that has more functions, has got a windows look and feel user interface, was based on new technology and linked to GIS. Nowadays all large enterprises and consultants involved in permitting and plans in the RMA use the data delivered by the I^2 database. The results of the computations based on I^2 data are widely accepted and appreciated by enterprises, consultants, citizens and authorities as it seems to be the acoustic truth for mankind in the RMA. Of course, when I^2 data are retrieved from the database and are handed over to the consultants there are some rules for mutating and

handling these data and also for the process of putting back the mutated data back into the database must be complied with. I^2 automatically checks the data that are put back into the database. The mutated data go through a calculation process before re-integration into the database. Update of I^2 data takes place when companies need an environmental permit or when spatial plans are made and assessment of the environmental impact is needed. Engineers seek DCMR EPA for a set of data to make their assessments by computation in order to determine the noise effects of their plans, requests for permits or other acoustic studies. When the computations are finished the mutated data model returns to DCMR EPA on order to be integrated in I^2. Only the plans that will be realised will be re-integrated, not eventual alternative scenario's that are calculated and discarded. In this way data in I^2 are kept up to date. This holds true for all industrial noise sources as well as for the relevant objects in the surroundings of the industrial area (dwellings etc.).

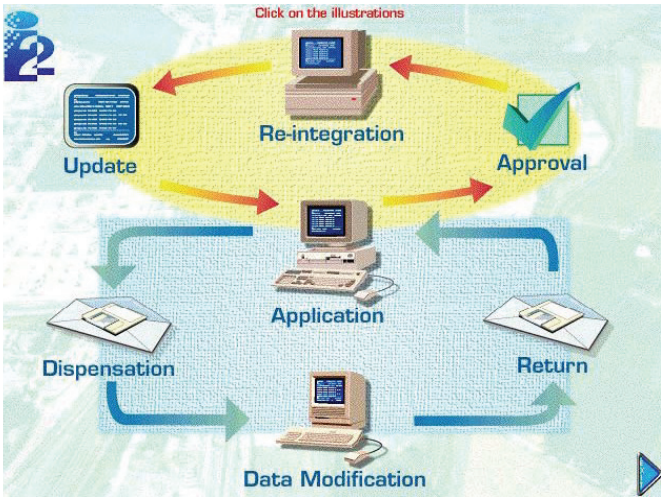


Fig. 1 *Lifecycle of I^2 data*

With the system I^2, still state of the art in The Netherlands, DCMR EPA can support its legislative noise tasks efficient and effective. These noise tasks are inter alia:

- Defining noise limits in environmental permits
- Management industrial acoustic zones and keeping the limits of that zones.
- Determination of noise aspects for spatial plans
- Computation of spatial scenario's.
- Determination of emissions for specific branches of industry.
- Monitoring the noise levels at the facades of dwellings near industrial areas by producing noise maps.

The main advantages of system I^2 to be reported in this paper are:

- The system can be used for multiple tasks as aforementioned.
- The system is at every moment up to date and can reproduce previous and historical situations.
- The acoustical, geographical and administrative data of the I^2 database are approved by the systems demands and the users of the system. Quality control is carried out at two levels. The first levels is done by the system, by algorithm that are included in the software. The second level is done by the user who has to fulfil the needed checks and has to approve the data.
- Within the RMA there is a standard for modeling. Authorities as well as consultants and enterprises are using the same acoustic model. This saves a lot of discussions, time and money.
- Within the RMA a standard for outdoor noise propagation software is established (Predictor). So, the data of the advisors is compatible with the system environment of the authorities.
- The system I^2 is accepted by all enterprises, the relevant authorities and the consultants hired by the enterprises to conduct the acoustics investigations.
- System I^2 doesn't only exist of software and hardware but also of "orgware " because the system is ran by a sort of a foundation. In this pseudo-foundation not only DCMR EPA participates but also the province of South Holland, the municipality of Rotterdam and the Rotterdam Port Authorities. A general manager is appointed who runs the daily business of I^2 and also an application manager is present within the I^2 organisation. The tasks of this application manager are to help the users with all kind of questions, to register the wishes of the users and report on the performance and security aspects of the system and run the needed tests. The application manager also reports management information (use, filling degree of database, deliverable time of models that are put out to advisors and so on).

3. SYSTEM I^2 AND NOISE MAPPING

Due to the last task mentioned afore, monitoring noise levels, it's just a small step to produce the EU noise maps. In the past decades, DCMR EPA has already produced noise maps for several purposes. Decision makers such as the ministry of Housing, Environment en Spatial Planning and the ministry of Transport, Public Works and Water management but also the National Bureau of Economic Policy Analysis (CPB) and the National Institute for Public Health and Environment have appealed on DCMR to make computations for their plans and investigations, because of the presence of I^2 [4,5]. Due to this system and the experience gained in previous projects it seemed rather easy to draft the industrial noise maps according to the END 2002/49/EC [6] for some of the cities in the RMA during the first round of noise mapping. Recently the noise maps for the second round of noise mapping as meant in the END 2002/49/EC have been completed.

4. NOISE, HEALTH AND MONEY

In cooperation with National Institute for Public Health and Environment (RIVM), the Dutch ministry of Housing, Environment en Spatial Planning and the Rotterdam Municipal Health Service DCMR EPA have carried out some

investigations on noise, health and money[7,8]. The health effects determined during this project are sleep disturbance, annoyance and high annoyance caused by noise. The study found relations between noise and annoyance, high annoyance, sleep disturbance and hypertension. Most annoying and sleep disturbing source was traffic noise as found in all European agglomerations. Almost 12% of the inhabitants of the Rotterdam region is highly annoyed by traffic noise. The industrial noise maps DCMR EPA produced are based on data from the I^2 system as mentioned before. The data were imported into a noise propagation model and with this model the noise levels were calculated on a grid around the industrial sites. With a Geographical Information System (GIS) the contours were visualized against geographical background. Since 2002 the GIS has been developed more and more and is now suitable for making all kind of noise and so called conflict maps. The GIS can be used for presentation, analysis, determination, etc. and is an excellent tool to determine the number of houses exposed to noise in a certain noise band, e.g. 55-60 dB. With this information and other information the number of people can be counted that is exposed to a certain noise band. With the help of so-called dose-effect-curves (e.g. Miedema) the number of annoyed, highly annoyed, sleep disturbed, etc. can be determined. This information can be required for policy making or reporting to the EEA Copenhagen [9] according to the END 2002/49/EC. Another exercition that can be executed on the information obtained by I^2 computations and data is to assess the loss of value of real estate properties that are exposed to high noise levels. In 2008 DCMR EPA carried out such a study.

5. FUTURE DEVELOPMENTS

Currently DCMR EPA is preparing a revision of system I^2. Beside improving the user interface, skipping redundant screen, applications and adding new features and functionalities the system will be turned in a web based system.

6. CONCLUSIONS

To conclude this paper sum some lessons learned in the past two decades can be summed up.

- System I^2, invented, designed and developed in the period 1992-1996 and taken into operation in 1996 is still state of the art.
- System I^2 is managing the industrial noise in the RMA in a proper way, results are reproducible and reliable which makes that stakeholders accept and appreciate the system and his results.
- Keeping a system as I^2 appreciated among the stakeholders and financiers goes not automatically, it needs many efforts!
- Reliable, up-to-date and compatible data is needed to gain results that have added value.
- To a certain extend making noise maps is just a technicality if we have the right instruments, software, methodologies, knowledge and input.
- Providers of data do not always cooperate with the organization that produces the noise and conflict maps.
- It is advisable to set up a database with data needed for producing noise maps en to keep this database up to date for the next round of noise mapping.
- Regarding the previous point it should be emphasised that good work procedures between the database owner and the deliverers are put in place.

7. REFERENCES

[1] H.Wolfert, Zone control as a first pace to noise mapping EU, EURONOISE 2006 Tampere.

[2] www.dcmr.nl

[3] Dutch Noise Act (Wet geluidhinder, 1979, Stb.99

[4] R.Maat DCMR EPA, Delta Plan Noise 1999, Schiedam

[5] A.M. van Wijk, R.Maat and H.Wolfert, Cost Benefit Analysis 2nd Maasvlakte, 2002, Schiedam

[6] Directive 2002/49/EC relating to the assessment and management of environmental noise on 25 June 2002, also known as the "END", European Commission, Brussels.

[7] R.G. de Jong, R.Slob. Monitoring Milieu en Gezondheid, fase 2, pilot regio Rijnmond, December 2004. MSR report, Schiedam/Rotterdam.

[8] H.Wolfert et al, Noise Health and Money, MSR report, 2008, Schiedam.

[9] The Noise Observatory of European Environmental Agency, http://noise.eionet.europa.eu/

УНИВЕРЗИТЕТ У НИШУ

ФАКУЛТЕТ ЗАШТИТЕ НА РАДУ У НИШУ

СТУДИЈСКИ ПРОГРАМИ

На основним академским студијама Факултет заштите на раду у Нишу изводи студијски програм под називом:

ЗАШТИТА РАДНЕ И ЖИВОТНЕ СРЕДИНЕ

Основне академске студије трају 3 (три) године,
а обим студија износи 180 ЕСПБ бодова. Савладавањем студијског програма студент стиче стручни назив „ИНЖЕЊЕР ЗАШТИТЕ ЖИВОТНЕ СРЕДИНЕ“.

На мастер академским студијама
Факултет заштите на раду у Нишу изводи пет студијских програма:

ЗАШТИТА НА РАДУ

ЗАШТИТА ОД ПОЖАРА

ИНЖЕЊЕРСТВО ЗАШТИТЕ ЖИВОТНЕ СРЕДИНЕ

УПРАВЉАЊЕ ВАНРЕДНИМ СИТУАЦИЈАМА

УПРАВЉАЊЕ КОМУНАЛНИМ СИСТЕМОМ

Мастер академске студије трају 2 (две) године,
а обим студија износи 120 ЕСПБ бодова. Савладавањем студијског програма студент стиче академски назив МАСТЕР ИНЖЕЊЕР
из одговарајуће области.



РЕПУБЛИКА СРБИЈА, Чарнојевића 10А, 18000 Ниш
Телефони: (018) 529-701, 529-805, 529-755, Телефакс: (018) 249-962
www.znrfak.ni.ac.rs

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

DESIGN OF NOISE PROTECTION OF INDUSTRIAL PLANTS-CASE STUDY OF A PLYWOOD FACTORY

Branko Radičević, Zoran Petrović, Slobodan Todosijević, Zvonko Petrović

University of Kragujevac, Faculty of Mechanical Engineering Kraljevo, Serbia, radicevic.b@mfkv.kg.ac.rs

Abstract *- The paper presents activities of reduction of noise emitted by plywood factory facilities. Dominant noise sources in the factory, which caused noise levels above limits, were identified. Based on calculation of acoustic fields performed by original software package, a noise map of the endangered area was created, and a noise protection system was designed. The noise protection system consists of two sound barriers, insulation of noise sources and changes of organization of the technology process. Application of the noise protection system led to reduction of specific noise levels for 14 dB. Noise levels at a control site in residential areas during day do not overcome limits anymore.*

Keywords*: industrial noise, noise maps, acoustic calculations, noise protection, noise barriers*

1. INTRODUCTION

By the example of a chip factory we presented the activities needed to be realized in order to successfully protect the residential area located near the factory. This and similar residential zones naturally sprang up after the factories had been built. Furthermore, the residential zones located in, or closely to the industrial area are difficult to classify into some of the legitimate acoustic zones. This leads to the introduction of a new acoustic zone for the residential areas near an industrial zone. Examples of similar solutions are known in some European countries. In this way the subjects of environment noise protection would be allowed to mutually cooperate and provide coordination in carrying out measures and decisions.

Total amount of noise level in residential area near the chip factory was 76 dB (A), which far exceeds the noise indicator values in an environment for the V acoustic zone. There are two causes for the far exceeding. The first is the short distance of the factories, and the second is the frequent city traffic artery between factories and residential blocks.

The noise polluted residential zone stretches parallel to the factory halls on the length of around 170 m. Approximate distance between the house facades and the nearest noise sources is around 35 m. Key problems in searching the most efficient method to protect from noise are: an enormous height of some of the factories (up to 25 m), great number of noise sources, distance of the houses and densely populated area. We measured the noise levels of all sources, and then established the dominant noise sources. By measuring the levels of all noise sources, adopting the dominant sources, establishing the type of noise source and weakening of noise through the space by building sound walls, a mathematical method has been formed to establish levels of noise and select the most suitable variant of noise protection considering the possibilities of technical realization.

2. SOURCES NOISE

2.1 Types of Noise Sources

Sources of the noise in factory according to its location can be conditionally divided into three groups:

The main noise sources are:

- the main compressor station and production power
- processing part which includes three subsystems: a line for sifting raw and dry chips, a line for measuring dust, a line for transport and sifting chip shavings
- chips preparations (a bridge crane, log transporter, mill)

Equipment and machines used in the process of chip production fall into group of stationary sources that generate high levels of noise. In the part of the factory that represents the dominant source of noise, three subsystems can be noticed: a line for sifting raw and dry chips, a line for measuring dust, a line for transport and sifting chip shavings.



Fig. 1 *Noise sources in the wood processing plant*

Raw chip is transported by rake and worm transporters from the silo to the dryer of outer layer (DS) and to the dryer of inter layer (MS). From the drier chip is pneumatically conveyed by the ventilator to the cyclone separator. First – the coarsest chip fraction is pneumatically conveyed back to the mill (PSKM). In the mill chip is being ground – fragmentized and pneumatically conveyed by the ventilator to

the cyclone separator from where, by the halt and systems of worm transporters is directed to the sifting grate – the sieve. The second and the third fraction are pneumatically conveyed to the drier chip silos of outer layer (DS) and inter layer (MS). The fourth chip fraction is the finest one (the dust) pneumatically conveyed by the compressor to the dust silo.

2.2 The Type of Noise

In search for successful model of noise control, evaluation of noise levels and taking adequate measures and methods for reduction of the noise, it is necessary to have the data about the characteristics of noise itself as exact as it is possible. These data are obtained by measuring characteristic noise values in frequency, amplitude, and time range. In order to establish precise noise characteristics, a series of noise measuring have been performed during day and night. Major mechanisms for generating noise in this case can be divided into two groups: mechanical (ventilators, compressors, electro motors, gear transmission, belt transmission, transporters, bearings, and other rotational components), and aerodynamic which are result of pneumatic chip transport. Machine tools of this type generate very high noise levels mainly characterized as tonal, with components ranging from medium to high frequency proportional to rotational speed of mechanical components. Aerodynamic noise is a result of chip motion under the influence of air circulation in pneumatic pipelines which connect silos of great heights (some may even reach 30 m height). Since the shavings in the pneumatic pipelines are moved with high speed through different cross sections and curves, it comes to turbulence, which generates wide belt noise.

2.3 Noise Level

The factory works around the clock with no pauses.

Table 1 *Dominant noise sources in the factory*

No.	Mark	Noise level [dB(A)]
S_1	Rake transporter of inter layer	81
S_2	Gear of rake transporter	81
S_3	Sifting grate – sieve	81
S_4	Dry chip Ventilator of inter layer	100
S_5	Dry chip Ventilator of outer layer	97
S_6	Vertical worm transporter	89
S_7	Horizontal rake transporter	89
S_8	Inter layer halts	89
S_9	Ventilator for extra chip drying	94
S_{10}	Rake transporter Z-silos	86
S_{11}	Log transporter	83
S_{12}	Crane (engine)	85
S_{13}	Reverse pipeline from the hall	85
S_{14}	Ventilator power 90 kW	87
S_{15}	Ventilator	81
S_{16}	Rake transporter 4 kW	80

The first base source is formed by the means of 29 sources divided in three already mentioned groups. Noise levels of particular sources are measured at very close distance (up to 0.5 m), in order to avoid influence of other sources. It should be pointed out that there are different noise sources in the factory which levels are less than 80 dB. Only noise levels from 80dB to 100dB are taken into consideration.

As a criterion for the choice of dominant sources, noise levels formed by the separate sources are taken, as well as their distance from residential area, the height of the source and their possible shelter from other objects (Table 1).

2.4 Noise Frequency Spectrum

In addition to measuring equivalent noise levels for characteristic sources, frequency noise analysis has been conducted. Localization of the noise source: chip preparation and the processing, frequent noise characteristic typical for the factory region is described by the means of 1/3 octave filters. The noise located on the chip preparation has an average equivalent level from 92 dB (A) and is wide belted, because it has an approximately even distribution of acoustic energy in a wider frequency spectrum. In the Fig. 2, the description of 1/3 octave frequency spectrum is given. The noise in the processing part of the factory is also wide belted. In the Fig. 3. The frequency characteristic on the platform of the drier is described, where can be seen that noise level is a bit higher regarding the lower and medium frequencies.

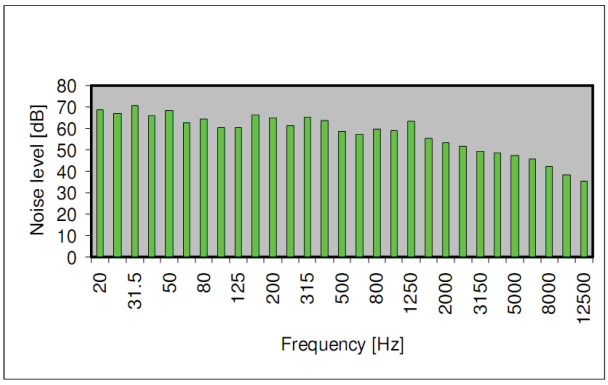


Fig. 2 *Frequency characteristic – plywood preparation*

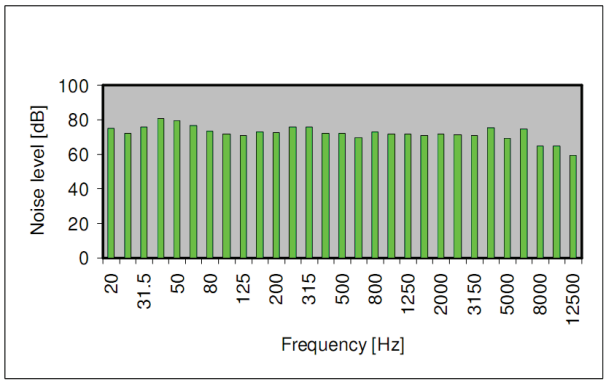


Fig. 3 *Frequency characteristic – drier platform*

Compressor station as third location of noise source isn't separately analyzed in terms of frequent analysis because the compressors are in objects made of bricks. Measuring has shown that is enough to keep windows on the compressor station closed. Under this treatment, the compressor station has no influence on the increase of noise level in the environment.

3. NOISE PROTECTION SYSTEM

In order to enable efficient design of noise protection system, it is necessary to form a mathematical model, which can be used for calculating a noise map for total area. The major advantage of forming the mathematical model is a realization

of variant acoustic solutions. These solutions, along with other limitations are a foundation for multiple criteria optimization when making choice about specific solutions for noise protection system.

3.1 Noise at the Checkpoints

By the series of measuring in the residential area, the checkpoint has been detected, i.e. the point where the level of noise is the highest in the entire residential zone. As the process of production ceaselessly continues, solution to the noise protection lies in exploring the protection system, which at the checkpoint in front of the residential block (in further analysis marked as KT1) provides the level of specific factory noise of 55 dB (A) which is a tolerable value of noise indicator in environment during night.

Table 2 *Noise level at control points*

Mea-suring point	Residual noise level [dBA]		Total noise level [dBA]		Tolerable noise level [dBA]	
	day	night	day	night	day	night
KT_1	63	53	76	73	65	55

If for the existing noise level we adopt the noise level established by measuring noise near the street, which separates the factory and residential area during night, we can calculate a specific noise level of the factory at the measurable checkpoints, i.e. in the residential area.

3.2 Noise Map

A necessity for the noise level to be calculated on various points and a need for parallel observation of different sources and barriers, led to the usage of software as a solution to the calculation of noise field. (1)

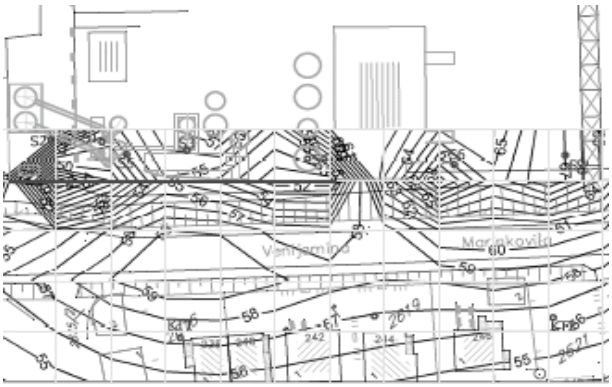


Fig. 4 *Noise map – a desired state*

The software enables calculation of noise field produced by multiple point noise sources, and their stretching is limited with several line barriers. A model for determination of noise field is based on the spatial model of the field used for the calculation of the noise level, the model of the source, and the model of the barriers. Noise field is described by the noise levels calculated in the points, which are part of the equidistant areas parallel to the basis of the field.

An algorithm has been formed to calculate the weakening during the spreading of the noise:

$$C = C_D + C_A + C_B + C_G + C_Z \qquad (1)$$

Weakening of the noise level is a result of the correction caused by: C_D - divergence of sound waves, C_A – air absorption, C_B – barrier, C_G – terrain absorption, C_Z – green areas.

For sofware application the noise sources (position and level of the noise), position of the barriers, and the position of the checkpoints need to be defined. As a final resul we get noise level in the knots of the web. The step in the web may be taken arbitrary, but usually the web 10x10 m is used as a noise map, Fig. 4. Noise map – a desired state.

3.3 Methods for Noise Protection System Project

In order to successfully project noise protection system we need to analyse active and pasive methods of protection through the effects provoked by the specific variants in the environment. Exact answers in terms of choice of the most efficient and most economic variant of noise protection, coordinated with technological and building projects, can be only given when analyzed parallelly with technoeconomic analysis of various variants.



Fig. 5 *Barrier and its base construction*

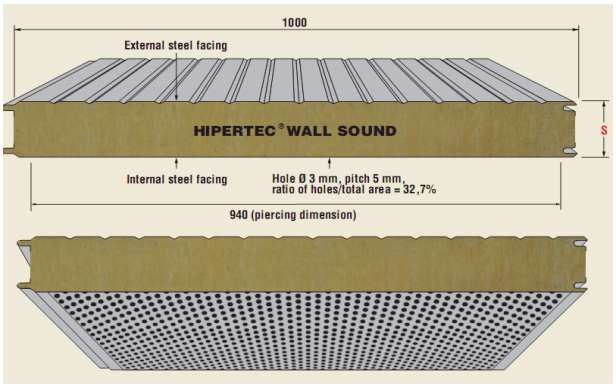


Fig. 6 *Chosen panel and its protective level*

When deciding about alternative solutions, we considered possibilities of technical realization of suggested variants. As a solution of the problem a combination of active and passive noise protection has been suggested. Building of the barriers 6 m high and 60 m long and active protection on the noise sources themselves, with height equal or higher from the barrier height, both represent the most rational solution to protect from the noise coming from the factories in the example mentioned above.

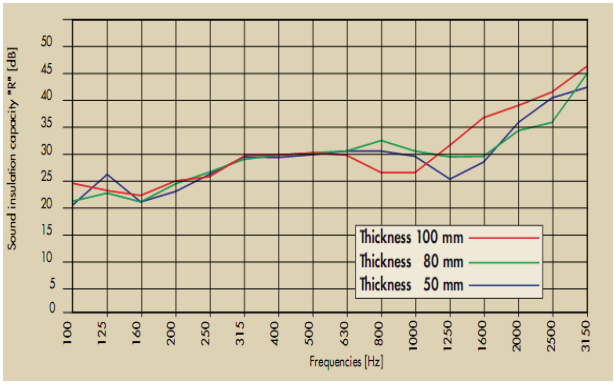


Fig. 7 *Isolating power of the panel*

To build a wall sound we took the panel 80 mm thick (pictures 6, 7), with one perforated surface (32,7%) facing the sources of the noise. Besides its great isolation power, the panel is also fireproof, which is very important here considering the fact that we are talking about chip factory, where the chances for fire are big.

3.4 Protection from Separate Noise Sources

Besides the two barriers, 6 m high and 108 m long, noise protection from separate dominant sources has been carried out. A criterion for establishing priorities in order to realize noise protection from separate sources primarily was acoustical. The protection from the noise sources, which produce the highest level of noise, or sources at the shortest distance to the residential area or sources located on the great height, has been carried out.

Separate sources included by the protection system are:

- Vertical worm transporter
- Ventilator for chip drier with interlayer
- Inter layer halts
- Ventilator for chip drier with outlayer
- Ventilator for extra drying of the chip

Some examples of the noise protection are presented in the figures 8, 9, 10 and 11.



Fig. 8 *Ventilator for chip drier with interlayer– after sound protection*

Above mentioned noise sources are protected by a shield, as displayed on the picture which represents vertical worm transporter, or protection is achieved by putting small barriers.

Protection made by shield of absorptive panels (the same panels as those used for the barrier), what can be seen on the example of vertical worm transporter (pict.9) gives lessening of noise level immediatelly behind the panel for 20 dB. The same goes for the small barriers made of the same panels and set in front of dominant noise sources. (pict.8)



Fig. 9 *Vertical worm transporter – before and after sound protection*

Barriers made of ribbed sheet metal give effect of lessening noise levels (immediatelly behind the barrier) for 8 dB. This solution is displayed at the example of inter layer halt of dry chips.



Fig. 10 *Inter layer halts – before and after sound protection*



Fig. 11 *Ventilator for extra drying of the chip – before and after sound protection*

Barriers made of ribbed sheet metal combined with rubber acoustic curtains (immediatelly behind the barrier) give effect of lessening noise levels for 6dB. (fig.11)

4. EFFECTS OF NOISE PROTECTION SYSTEM

Carrying out the protection measures, relevant noise level of the factory has been realized and it does not exceed tolerable limit of 65 dB during daily working conditions. Further protection measurs are to be taken in accordance with recommendations given in this paper, in order to reach tolerable limit of 55 dB for night.

Effects of lessening of noise levels on the checkpoint are displayed in the following table:

Table 3 *Effect of reductionof total noise level in the factory after realization of projected measures of noise protection*

Tipe of Protection	Noise level dB(A)		Reduction of Total Noise Level dB(A)	
	Before protetction	After protetction	Separately	Cumulatively
Two bariers (6x108 m)	76	69	7	7
Five dominant noise sources	69	66	3	10

Total noise level in the residential area on the checkpoint is lessened for 10 dB (A), starting from the beginning of realization of projected measures for noise protection. This means reduction of the total noise level of the factory for 3.16 times, i.e. 316.2%.

Table 4 *Effect of reductionof specific noise level in the factory after realization of projected measures of noise protection*

Tipe of Protection	Noise level dB(A)		Reduction of Specific Noise Level dB(A)	
	Before protetction	After protetction	Separately	Cumulatively
Two bariers (6x108 m)	76	69	8	8
Five dominant noise sources	69	66	6	14

The specific noise level on the checkpoint has been lessen for 14 dB(A), starting from the beginning of realization of projected measures for noise protection. This means reduction of the specific noise level of the factory for 5 times, i.e. 501.2%.

5. CONSLUSION AND DIRECTION OF FURTHER PROTECTION ACTIVITIES

By measures of noise protection, a specific factory noise level of 62 dB has been realized. Reducing the noise level to 14 dB has considerably improved acoustic comfort in the residential zone near the chip factory. This level of noise is in a range of tolerable values for noise indicator in the environment, refferring to time period during a day. Since the factory works around the clock, it is necessary to take extra measures in order to protect from noise and thus reach tolerable noise level during night.

The directions of further actions is difficult to realize at this point, because there is a large number of point noise sources with levels around 80 dB and they are located on great heights. Moreover, there are several rake transporters, which practically represent line noise source and they need to be isolated by entire length. Some of the possibilities are connecting elastic pipelines to the basis of huge electromotors and fans.

Above presented example confirms that by design the noise protection system great effects can be achomplished in terms of reduction of noise level in the environment.

6. REFERENCES

[1] Petrović, Z., Radičević, B.,Šoškić Z., Bjelić, M. – The protection from the noise of industrial plants - Noise and vibrations, XXI Conference with international participation, Tara 2008.

[2] Petrović, Z., Radičević, B., Bjelić, M., „ The proposal for the solution for protection from noise *ŠPIK IVERICA FANTONI GROUP" - Ivanjica"*, University of Kragujevac, Faculty of Mechanical Engineering Kraljevo, 2007.

[3] M. Kolarević, Z. Šoškić, Z. Petrović, B. Radičević: *Noise Protection In Urban Environment- Description Of A Project*, Mechanics, Transport, Communications, Academic journal, Todor Kableshkov University of Transport, Sofia, ISSN 1312-3823, issue 3/2011, pp.IV-69-IV-78.

[4] Praščević, M., Cvetković, D., " *Environmental Noise "*, University of Niš, Faculity of occupational Safety Niš, 2005

[5] B. Kotzen, C. English: *Environmental Noise Barriers, A guide to their acoustic and visual design*, Second edition, Taylor & Francis e-Library, London and New York, 2009.

[6] Uzunović, R., „*Protetction from Noise and Vibration"*, LOLA Institute, Belgrade,1997

[7] Veličković, D., „*Noise and Vibration 2"*, University of Niš, Faculity of occupational Safety, Niš, 1990

[8] Standards: SRPS ISO 1996-1 and SRPS ISO 1996-2

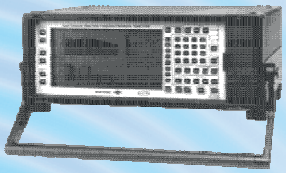
Acknowledgement: The paper is a part of the research performed within the project TR37020. The authors would like to thank to the Ministry of Education and Science of the Republic of Serbia for supporting this research.

CENTAR ZA TEHNIČKU DIJAGNOSTIKU & LABORATORIJA ZA BUKU I VIBRACIJE

UNIVERZITET U NIŠU
FAKULTET ZAŠTITE NA RADU U NIŠU
Čarnojevića 10a, 18000 Niš
Tel.: 018 529-747; Fax: 018 529-748

Merenje i analiza nivoa buke

- Određivanje ekvivalentnog i merodavnog nivoa buke u zavisnosti od karaktera buke i vremena izloženosti;
- Frekvencijska analiza nivoa buke;
- Statistička analiza nivoa buke;



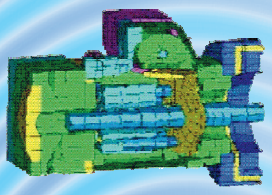
Merenje i analiza nivoa vibracija

- Određivanje merodavnog nivoa vibracija;
- Frekvencijska analiza nivoa vibracija;



Merenje i analiza akustičke aktivnosti mašina

- Određivanje nivoa zvučne snage u realnom ambijentu merenjem intenziteta zvuka;
- Određivanje nivoa zvučnog pritiska merenjem intenziteta zvuka;



Preventivno održavanje mašinske opreme

- Praćenje stanja mašinske opreme na osnovu nivoa zvuka;
- Praćenje stanja mašinske opreme na osnovu nivoa vibracija;
- Balansiranje rotirajućih elemenata mašinskih sistema;





Projektovanje vibroakustičke zaštite

- Projektovanje sistema za izolaciju i apsorpciju zvuka;
- Projetovanje sistema za vibroizolaciju;
- Projektovanje akustike prostorija;

Merenje i analiza akustičkih karakteristika prostorije

- Vreme reverberacije;
- Izolaciona moć pregradnih zidova i konstrukcija:
- Izoalaciona moć od zvuka udara;
- Koeficijent apsorpcije materijala;

Sistematsko merenje komunalne buke

- Frekvencijska, statistička i procentualna analiza nivoa buke u komunalnoj sredini;
- Zoniranje urbanih prostora u odnosu na nivo buke;
- Izrada strategijskih akustičkih mapa;
- Ispitivanje uticaja akustičke aktivnosti instalirane opreme u javnim objektima na životnu sredinu;





Obrazovanje

- Instruktivni seminari;
- Studije za inovaciju znanja;
- Specijalističke studije;



University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

DESIGN OF NOISE PROTECTION IN URBAN AREAS- CASE STUDY OF AN ELEMENTARY SCHOOL

Zoran Petrović[1], Branko Radičević[1], Zvonko Petrović[1], Nebojša Zdravković[1]

[1] University of Kragujevac, Faculty of Mechanical Engineering Kraljevo, Serbia, petrovic.z@mfkv.kg.ac.rs,

Abstract – *The paper describes the activities to eliminate the impact of noise on the operation of an elementary school. By measuring the noise outside and inside the premises, values of noise levels were determined. On the basis of acoustical calculation software noise maps were drawn and used to design noise protection system. In this case the protection systems is designed as a sound barrier, and replacement of windows on the building was proposed. When designing the barrier, in addition to the acoustic requirements, aesthetic, urban and safety have been also considered and presented in the paper.*

Key words: *Noise mapping, Noise protection, Sound barriers.*

1. INTRODUCTION

Sound is of interest to many scientific disciplines, ranging from engineering to medical and human research. In the field of engineering dominate three aspects of interest:

- Sound as a mean of communication,
- Sound as a manufacturing tool,
- Sound as a noise.

The European Union defines noise as unwanted or harmful sound from external environment created by human activities. This usually refers to:

- Traffic noise,
- Noise generated by the industry in cities and towns,
- Street noise created by: construction machinery, music equipment in restaurants and other entertaining facilities, sporting events, other outdoor facilities, loading and unloading of various metal objects, etc.,
- Noise in households (from electrical and other appliances, from neighboring houses and similar).

Noise above the permissible limits, which occurs around the school facilities, negatively affects students and teachers, reducing their physical and mental abilities. Prolonged or loud noise may directly or indirectly cause not only hearing losses, but also other diseases and disorders, and here are presented only a few:

- Irregular heartbeat,
- Loss of appetite,
- Depression,
- Nervousness,
- Insomnia,
- Raised blood pressure,
- Raised level of sugar in the blood,
- Damages to the blood vessels,
- Damages to the nervous system,
- Irritability,
- Stress,
- Reduced ability to work,
- Chronic fatigue,
- Reduction of attention and memory.

All these symptoms indicate that exposure to noise above the permitted level are very dangerous for children in schools. Research of the Institute of Hygiene and Environmental Medicine, Faculty of Medicine in Belgrade, confirms that the noise in recent decades belongs to the most important causes of damage to the health of residents of Serbian cities [1]. Research has shown that, in comparison with children from suburbs, kids in central areas of cities have higher blood pressure because of the noise.

In this paper we analyzed the noise that affects the elementary school. The research consists of the following four phases:

- measurements of noise inside and outside off the school,
- analysis of the sources of the noise,
- drawing of the noise maps, and
- design of noise protection barrier.

2. NOISE SOURCES

Elementary school is located alongside the regional road Kraljevo-Kragujevac and close to the workshops of Automobile Association of Serbia (AMSS). On the opposite side of the road is a bus stop.

The main sources of the noise are:

- **Traffic on the main road** that has four lanes (two in each direction). All categories of road vehicles use the road and the speed limit is 40 km/h. A crossroad with traffic lights is only 50 meters from the school, so the limit is generally well respected. However, because of the high intensity of the noise that occurs when starting the vehicle at traffic lights turn on and the bus station.
- **Noise from pupil** in the schoolyard during classes in Gymnastics
- **Workshop of Automotive Association of Serbia**.

The measurement revealed that the dominant source of noise is the main road. Therefore, during drawing of the noise maps is taken into account only the noise generated by the traffic.

Fig.1. shows the location of the school and point sources of noise tagged with S1 to S15, simulating noise emission by the vehicles at the road. KT1 and KT2 labels the positions of the control points where the noise level was tested (Table 1).

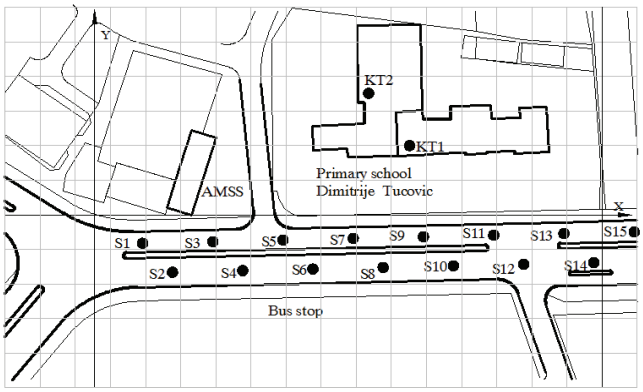


Fig. 1 *Position of the school and the point sources of noise.*

Besides, the measurements were taken outside and inside the school, in the classrooms given in the Table 1.

Table 1:

Measuring point	Buka	Vreme merenja	Ekvivale. nivo buke db	Ocena
Classroom no. 7 cabinet for mathematics (KT4)	Unutrasnja	10^{20}–10^{35}	**42.1**	Ne zadovoljava
Classroom no.7 cabinet for mathematics (KT1)	Spoljasnja	10^{40} – 10^{55}	**66.2**	Ne zadovoljava
Classroom no. 6 Cabinet of Physics (KT3)	Unutrasnja	11^{00} – 10^{15}	**44.6**	Ne zadovoljava
Classroom no. 6 Cabinet of Physics (KT2)	Spoljasnja	11^{20}–11^{35}	**57.6**	Zadovoljava

Data on the measured noise levels are given in the Table 2:

Table 2 *The measurement results*

Sources	X [m]	Y [m]	sound level L[db]
S1	12,89	8,22	75
S2	21,4	16,62	75
S3	32,97	7,76	75
S4	41,41	16,15	75
S5	52,89	7,29	75
S6	61,41	15,68	75
S7	72,9	6,83	75
S8	81,42	15,22	75
S9	92,90	6,36	75
S10	101,42	14,75	75
S11	112,9	5,9	75
S12	121,41	14,29	75
S13	132,42	5,43	75
S14	141,41	13,82	75
S15	152,91	5,96	75

On the basis of the measurement data and the modeling of the traffic noise by the point sources, noise maps of the current situation (Fig. 2) and the facade of the school (Fig. 3) are made.

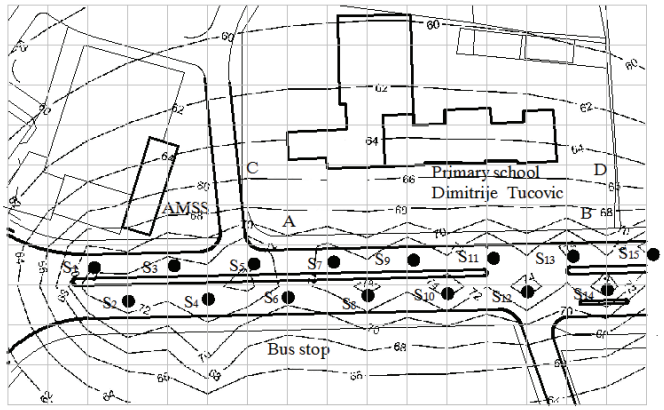


Fig. 2 *Noise map of the current state at the school*

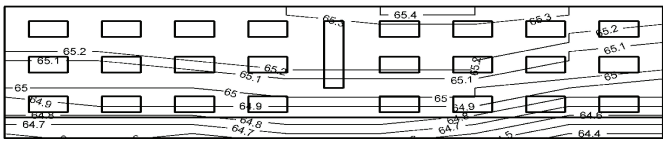


Fig. 3 *The noise level of the current situation on the facade of the school*

The figures show that the school is exposed to noise levels higher than it is allowed. Based on the above mentioned data and the noise maps were analyzed solutions for protection against the noise in the form of a sound barrier.

To this purpose were made noise maps which take into account the effects of a barrier with position as given to Fig.4.

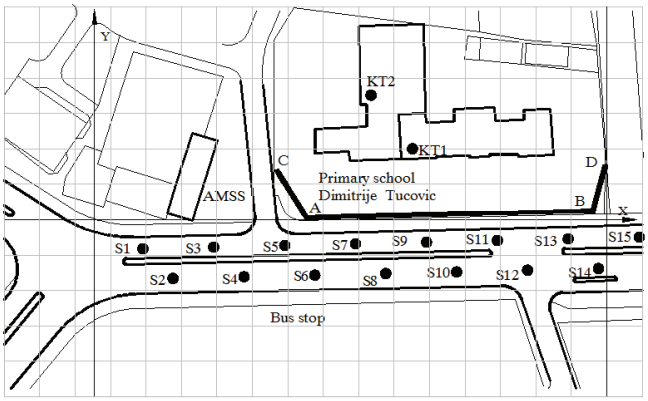


Fig. 4 *Position of the noise barrier and points A, B, C and D*

The respective noise maps with noise barrier are shown in the Fig. 5 and Fig 6. The noise barrier consists of three sections: AC, AB and BD. The coordinates of these points are given in Table 3.

To obtain the data that are used to draw the noise maps was used the software that was designed by the Faculty of Mechanical Engineering Kraljevo within the project TR 37020 of Ministry of Education and Science.

Table 3 *Data on barrier:*

	X [m]	*Y [m]*	*h [m]*
Barijera AB	$X_A = 57.93$ $X_B = 140.34$	$Y_A = 0$ $Y_B = 2$	7.3
Barijera AC	$X_A = 57.93$ $X_C = 50.11$	$Y_A = 0$ $Y_C = 14.23$	7.3
Barijera BD	$X_B = 140,34$ $X_D = 143,22$	$Y_B = 2$ $Y_D = 13.77$	7.3

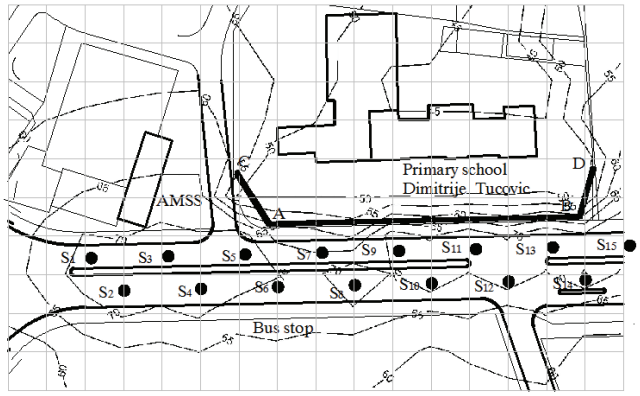


Fig. 5 *Map of the noise outside the school with the noise barrier*

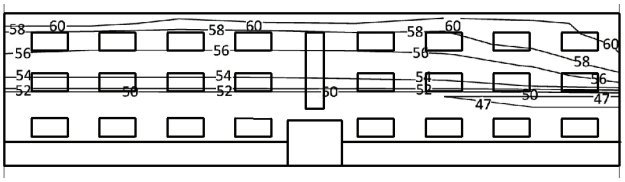


Fig. 6 *Noise maps of the facade of the school with the noise barrier*

3. DESCRIPTION TECHNICAL BARRIERS

Acoustic requirements, such as absorption capacity, efficiency, atmospheric effects, and size of the barriers, are of the primary importance in the design of the protective barriers. Length and height of the barriers are calculated to provide sufficient, that is the necessary, protective efficiency. In Fig.7 is shown the direction of the sound from the farthest vehicle lane to the school. The sound lines from other lanes are closer and the noise is more attenuated, and therefore, they have less impact to the noise affecting the school. Details of noise impact from the road to the school building are provided in versions with and without barriers in the previous chapter.

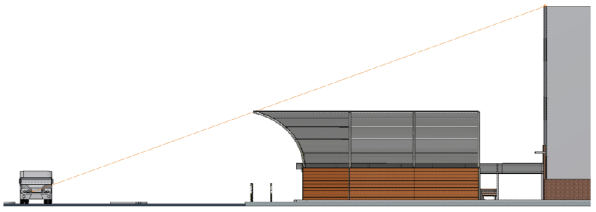


Fig. 7 *Profile of the noise barrier*

Raising of the barrier at the edges of the schoolyard reduces the wind force in the schoolyard, so the pupils will have comfortable walk and rest. As barriers have the form of a circular arc surrounding the sidewalk in the front of the school, they also protect the sidewalk from the influence of the rain. The slope of the barrier is made steep enough to provide safety against the load from snowfalls during winter.

Sound barrier is designed as a combination of sound absorption and sound reflection surfaces. The lower part of the barrier, up to the height of 2 m, is made of metal sandwich panels filled with mineral wool. The panels are perforated at one side and the side faces the sound source, in order to absorb the noise. The upper part of the arc is made of Lexan with thickness of 28 mm so that it reflects the sound towards the road, and not to the apartment buildings across the street.

Sound barrier, in full length of 100 m, with a projected height of 7.30 m, is slightly curved at the ends, which should eliminate the effect of sound diffraction of distant sound sources. Angle of distant sound sources to the facade of the school is less than $10°$.

Aesthetic requirements are met by construction of the barrier using modern materials and colors combination, with the aim to create attractive visual impression. The bottom of the barrier is made of metal panels allowing painting in various colors and leaving possibly for painting of murals or graffiti to match the needs of education process. Bearing construction is made from stainless steel and metallic materials that provide a nice look. At top of the barrier are mounted elements of transparent or slightly tinted Lexan. In this way, the schoolyard obtained a kind of intimacy, and on the other hand, views from the school, or the view from the road to the school remain open. The construction of the barrier did not comprise any damage to the trees in the park in front of the school.

Surroundings of the school, besides the road with four lanes, consists of the residential area and the new church on the same side of the road, while on the other side of the road are apartment buildings with commercial space. Configuration of the terrain is flat. Legislation would have to be explored in

terms of covering the sidewalk on the street as part of the public area. Other parts of the barrier are in the school yard. Compatibility with local appearance is achieved using metal construction barriers, similar to the metal fence around the church. Barrier's compliance with the road alignment is complete, because the barrier and the school building are parallel to the axis of the road.

In addition to the protection against the noise, the barrier construction has other facilities. The area between the entrance to the schoolyard from the side of the road and the entrance to the school is made through the barrier so that it is covered by a roof and equipped with benches. The purpose of the passage is to get together the youngest pupils with teachers or parents before crossing the street (Fig. 8).

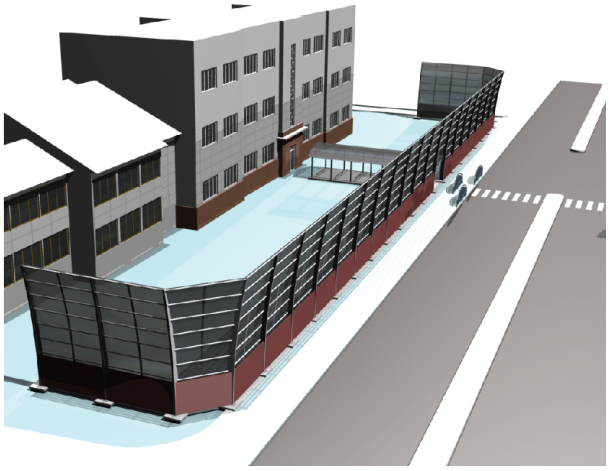


Fig. 8 *Noise barrier in the school*

Besides, on the sidewalk in front of the exit of the schoolyard is set a labyrinth with protective structure. It directs the flow of pedestrians from the street through a crossing, and prevents the unwary persons to get to the street (Fig. 9).

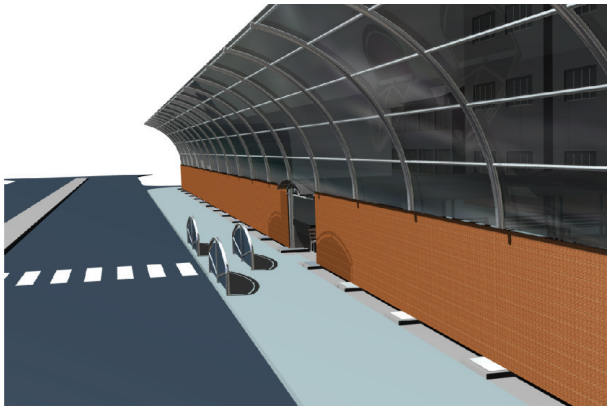


Fig. *9* *Look of the noise barrier*

The construction relies on the foundations below the columns, so to be resistant to temperature changes. Load capacity of the barriers is calculated considering the influence of weather, following the regulations in the field. The removal of water from precipitation running off barrier shall is made by a concrete channel placed below the construction in the schoolyard.

Pupil safety is increased by the barrier both in terms of traffic and possible people on the sidewalk. Sight distance for drivers and pedestrians is not reduced. The effects of light and shadows and the light reflections were considered. Visibility of animals and birds is provided by tinted Lexan. The materials used in manufacturing of the barrier are non-flammable and self-extinguishing.

Environmental factors of the barrier were considered by reducing the noise impact on pupils and school staff, as well as by the reduction of impact of exhaust gases from motor vehicles to the schoolyard and to the classrooms.

Maintenance of the barriers, in terms of atmospheric effects during long periods of use is easy because the barriers use materials resistant to the influence of rain, snow and wind. Transportation costs of materials, equipment and people are minimized and the construction work may be carried out during the school holidays, so as not to interfere education process.

The technology of the construction is devised so that all works on the barrier can be performed by the local contractors, without requiring special technologies.

3.1 Calculation of protection

The attenuation of the noise barrier is determined by the difference in the lengths of diffracted wave path and the direct wave path.

Attenuation of the barrier is calculated according to the standards for road traffic noise prediction (RSL 90) and industrial noise (ISO 9613), has the form:

$$C_B = -7 \cdot \log\left[5 + \left(\frac{70 + 0.25 \cdot s_\perp}{1 + 0.2 \cdot z_\perp}\right) \cdot z_\perp \cdot K_{w\perp}^2\right] \quad (1)$$

where $z_\perp$ – represents the path difference and $K_{w\perp}$ – the metrological correction.

The path difference between the length diffraction and direct path is:

$$z_\perp = A_\perp + B_\perp + C_\perp - s_\perp \quad (2)$$

Where are: $A_\perp$ – the source distance to the top of the barrier, $B_\perp$ – the distance to the top of the receiver barriers, $C_\perp$ – the sum of distances between the edges of the barriers, $s_\perp$ – the shortest distance to the receiving point of emission.

Metrological correction is determined based on the same parameters given by:

$$K_{w\perp} = \pi \cdot \left(-\frac{1}{2000} \cdot \sqrt{\frac{A_\perp \cdot B_\perp \cdot s_\perp}{2 z_\perp}}\right) \quad (3)$$

Equation (1) gives the total attenuation of noise levels. The frequency characteristics of noise attenuation barriers can be determined by the equation:

$$C_B = \begin{cases} \left[-20 \log \frac{\sqrt{2\pi N}}{\tanh \sqrt{2\pi N}} + 5\right] & N \geq -0{,}2 \\ 0 & N < -0{,}2 \end{cases}, \quad (4)$$

where N is the Fresnel-number, which is determined on the basis of ratio between the sound paths difference and their wavelength:

$$N = \pm \frac{2}{\lambda}\left(A_\perp + B_\perp + C_\perp - s_\perp\right) \quad (5)$$

4. CONCLUSION

This paper presents the protection against noise based on the construction of a barrier between a school and a road. The effects of the solution are reduction of the noise level and provision of improved environment protection of pupils and teachers. It also affects be the arrival and departure of pupils and parents from the school.

By comparing the maps with and without noise barriers, it can be seen that the noise levels are reduced by almost 20 dB around the school. At the street facade, the noise levels are reduced by 5 dB on top and 17 dB on the bootom. This shows that the use of barriers to reduce noise is effective and economic solution.

Structural barrier is rather simple, and therefore cost of construction of the structure is relatively small. It is easy to maintain and has a long life because of the materials that are resistant to corrosion and to the impact of the rain, snow and wind.

Acknowledgement: The paper is a part of the research made within the project TR37020. The authors are grateful to the Ministry of Education and Science of the Republic of Serbia for supporting this research.

REFERENCES

[1] http://www.novosti.rs/vesti/beograd.74.html:218457-uka-dize-pritisak

[2] M.Praščević, D.Cvetković: *Environmental Noise*, University of Niš, Fakultet zaštite na radu, Niš, 2005.

[3] B. Kotzen, C. English: *Environmental Noise Barriers , A guide to their acoustic and visual design*, Second edition, Taylor & Francis e-Library, London and New York, 2009.

[4] G.G. Fleming, H.S. Knauer, Cynthia S.Y. Lee, S. Pedersen: *Noise Barrier Design Handbook, Highway Traffic Noise*,

[5] M. Kolarević, Z. Šoškić, Z. Petrović, B. Radičević :*Noise Protection In Urban Environment- Description Of A Project*, Mechanics, Transport, Communications, Academic journal,Todor Kableshkov University of Transport,Sofia, ISSN 1312-3823, issue 3/2011, pp.IV-69-IV-78.

[6] Petrović, Z., Radičević, B.,Šoškić Z., Bjelić, M. - Protection against noise industrial plants - Noise and vibration XXI conference with international participation, Tara 2008



University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

NOISE PROTECTION MEASURES IN THE TERRITORY OF NOVI SAD DURING RECONSTRUCTION, MODERNIZATION AND CONSTRUCTION OF THE STARA PAZOVA - NOVI SAD DOUBLE TRACK RAILWAY LINE

Aleksandar Gajicki[1], *Ružica Ilić*[2]

[1] Institute of Transportation CIP, Nemanjina 6,11000 Belgrade, Serbia, gajickia@sicip.co.rs
[2] Institute of Transportation CIP, Trg Nikole Pašića 8, 11000 Belgrade, Serbia, rilic@sicip-trg.com

Abstract - *The plan of reconstruction and modernization of the railway corridor X, as one of national priorities, provides the reconstruction and modernization of existing railway lines in high-performance mixed traffic double-track lines with the designed speed of 160 km/h, and where is a possible 220 km/h. Part of this plan is the improvement of one-track railway line from Stara Pazova to Novi Sad with a total length of 42 kilometers. The paper discusses the current state of the environment in terms of noise, and possible impacts during construction and exploitation of the railway line on the territory of the city of Novi Sad from km 67+513 to km 77+656. Based on the obtained results protective measures are planned to reduce negative noise impacts on the environment.*

1. INTRODUCTION

The (Belgrade) - Stara Pazova - Novi Sad - Subotica - Hungarian border railway line links railway junctions of Belgrade, Novi Sad and Subotica. Total length of railway lines in the Corridor X passing through the Republic of Serbia is 864.6 km, and the (Belgrade) - Stara Pazova - Novi Sad - Subotica - Hungarian border railway line makes up about 17% of the length. The aim of upgrading the 42 km of railway line connecting Stara Pazova and Novi Sad (and Subotica in the future) is to make the railway transport more competitive and to reduce the difference in travel time between road and railway transportation, as well as to redirect the international road transportation to the railway, which shall result in improvement of the environment.

Rehabilitation of the existing track and construction of a new one on the section between Stara Pazova and Novi Sad is envisaged, with design speed of 160 km/h and where is a possible 220 km/h. Increase of speed shall not be possible on the railway section passing through the territory of Novi Sad (which is the subject of this paper), due to the present situation. On this section, the design speed shall remain between 80 and 100 km/h.

The railway runs through Petrovaradin, crosses over the Danube River and enters the city of Novi Sad. The terrain is mostly flat, with high degree of development. When impact of noise from railway traffic on the environment was analyzed, a 300 m wide corridor to the left and right-hand side from the railway was taken into consideration. On the studied area, there are 1.783 housing facilities which may suffer from the noise.

The overall objective we wish to achieve is protection and sustainable usage of the basic environmental factors. From the aspect of the railway traffic generated noise, the objective is to reduce the exposure of population to the negative impacts of high noise levels. The number of housing facilities in the area with increased noise level was used as the primary indicator for assessing the impact of noise.

A partial view of the existing conditions is shown, based on the taken measurement of noise level in the Petrovaradin station, for purposes of comparison with the planned. Calculation of noise indicators was performed with estimated data regarding traffic volume, characteristics of the new railway line and 3D terrain model from the Preliminary design for the reconstruction, modernization and construction of the Belgrade-Subotica railway line, section Stara Pazova - Novi Sad [1]. For calculations and for generating noise maps, the "Predictor-LimA Software Suite - Type 7810" software package was used. The estimate of noise annoyance in the territory of Novi Sad and Petrovaradin was performed according to the LKZ-method (Noise-Evaluation-Index-Method).

In order to ensure the legally prescribed noise level near residential and other structures sensitive to noise, measures for noise protection are envisaged in order to further reduce its negative impact on the environment.

2. TRAFFIC NOISE

The dominating sources of traffic noise in the studied corridor, apart from the railway line, are sections of arterial, regional and local roads running through the corridor, as well as city streets and industrial plants.

In order to determine the impact of the railway line, only the noise generated from the railway traffic was studied, while other sources of noise were not taken into consideration.

Acoustic zoning of the area in question has not been performed. In order to enable further analysis, and in line with the intended purpose of the area, it was presumed that it belonged in the zone 5 (city center, trade, commerce, administrative zone with residential buildings, zone along highways, arterial roads and city streets). Limiting values of

noise indicators in the open area during the day and evening hours are 65 dB(A), and 55 dB(A) during the night.

2.1 The existing condition

According to the previous information, issues related to traffic noise in the studied area are not significant in number, but there is no detailed information since until now no adequate systematic measurements of the noise level in urban environment were undertaken.

At the time of construction of the railway section from Stara Pazova to Novi Sad, there was no systematic and legally regulated approach to the environmental impact assessment (both negative and positive). Possible environmental issues in terms of noise resulting from construction and operation were not resolved.

In order to determine the urban noise levels in the environment resulting from passing trains, results from urban noise level measurement on the Čortanovci - Petrovaradin section taken for purposes of preparation a study for the World Bank were used [2].

This measurement was performed on 02/03.10.2007 between 20^{00} and 18^{00} hours. The measuring point was on the front wall of the Petrovaradin station, on the first floor, at 12 m distance away from the railway center line, and 3.5 m above the top surface of the rails. The background noise intensity was about 42 dB(A). Trains were running on the repaired section.

Statistical overview of test results on the measuring point was as follows:

- The equivalent 15-minute noise level ($L_{Aeq,15\ min}$) during the daytime was between 62.7 and 79.2 dB(A), and between 44.2 and 77.8 dB(A) during the night;
- The equivalent 60-minute noise level ($L_{Aeq,60\ min}$) during the daytime was between 57.9 and 76.2 dB(A), and between 42.3 and 75.9 dB(A) during the night;
- The maximum noise level ($L_{Fmax(A)}$) during the passage of one train in the daytime was between 85.8 and 106.2 dB(A), and between 61.8 and 102.9 dB(A) in the night;
- The equivalent noise level during the day is 69.8 dB(A) and 71.5 dB(A) during the night;

The equivalent noise level for the night time exceeds the legal limits for 16.5 dB(A). Maximum noise levels during individual train passage also represent an important factor in population annoyance.

Individual noise measurement does not and cannot illustrate the actual condition, but may be used to assess it. Based on one all-day measurement we can determine with 90% certainty that the obtained equivalent noise levels are within ± 10 dB range of the actual annual equivalent levels [4].

Bearing in mind accuracy of measurement of the equivalent noise level during the night, legal limits may be exceeded for 6.5 dB(A), but also for 26.5 dB(A). At any rate, population living in the vicinity of the railway is more or less exposed to the negative impact of noise.

We believe that the existing condition of noise level generated by railway traffic may only be determined on the basis of measurements. Application of computing methods for calculating noise levels, in particular the German method SCHALL 03, provides smaller values than real ones. This is the result of the unconformity of the specific methods to conditions in which the Serbian railway operates. For example, the method implies that the rails and wheels are in good working order, properly maintained, which in reality is not the case.

2.2 Future condition

The effect on the noise level in the environment resulting from construction of the second track and reconstruction the existing one on the Stara Pazova - Novi Sad section and its future operation in the territory of Novi Sad is twofold. The first includes noise during construction/reconstruction of the railway, and the second noise generated from operation of the railway traffic. The effects of individual segments on the environment shall overlap. Railway traffic on the existing track shall continue during construction works on the new one.

2.2.1 Noise during construction works

Noise levels during construction of the new railway track and reconstruction of the existing one shall largely depend on the number and kind of the deployed construction machinery, their position and distance from housing facilities in the impact zone. Since for this level of designing, organization and technology of construction works have not yet been defined, modeling and analysis of possible effect of noise on the environment was not performed. In any case, during construction/reconstruction of railway tracks it is necessary to carry out the noisier construction works during normal working hours where possible, to use the quietest available equipment, to use temporary noise barriers (if feasible), to educate the staff on construction site about noise effects, to move the noisiest machinery away from housing facilities, to organize transportation of material to and from the site during the operating hours on the site, to advise the population about forthcoming noisy operations etc. During execution of works, intermittent measurement of noise levels shall be conducted in order to determine whether the generated noise levels exceed the legal limits.

2.2.2 Noise during operation of the railway

For calculations and for generating noise maps, the "Predictor-LimA Software Suite - Type 7810" software package was used. German prediction model for railway noise „SCHALL 03 - Richtlinie zur Berechnung der Schallimmissionen von Schienenwegen“ was adopted. This method is in compliance with the 2002/49/EC Directive and Decree on noise indicators, limit values, method for assessment of noise indicators, disturbance and harmful environmental impact of noise ("Official Gazette of the RS", No. 75/10) because it produces results comparable with the recommended calculation methods.

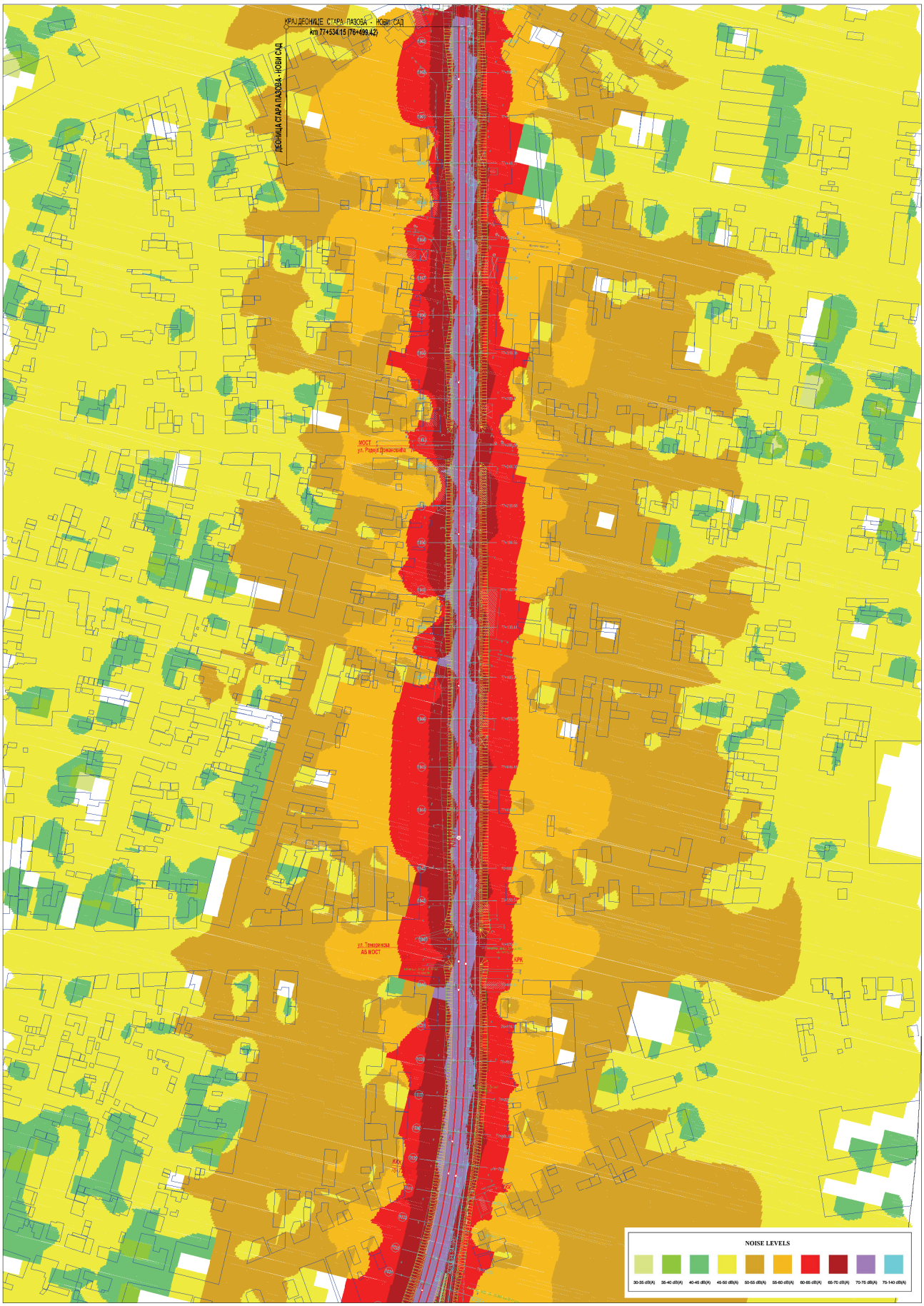


Fig. 1 *Noise map for night period before implementing noise protection measures (detail)*

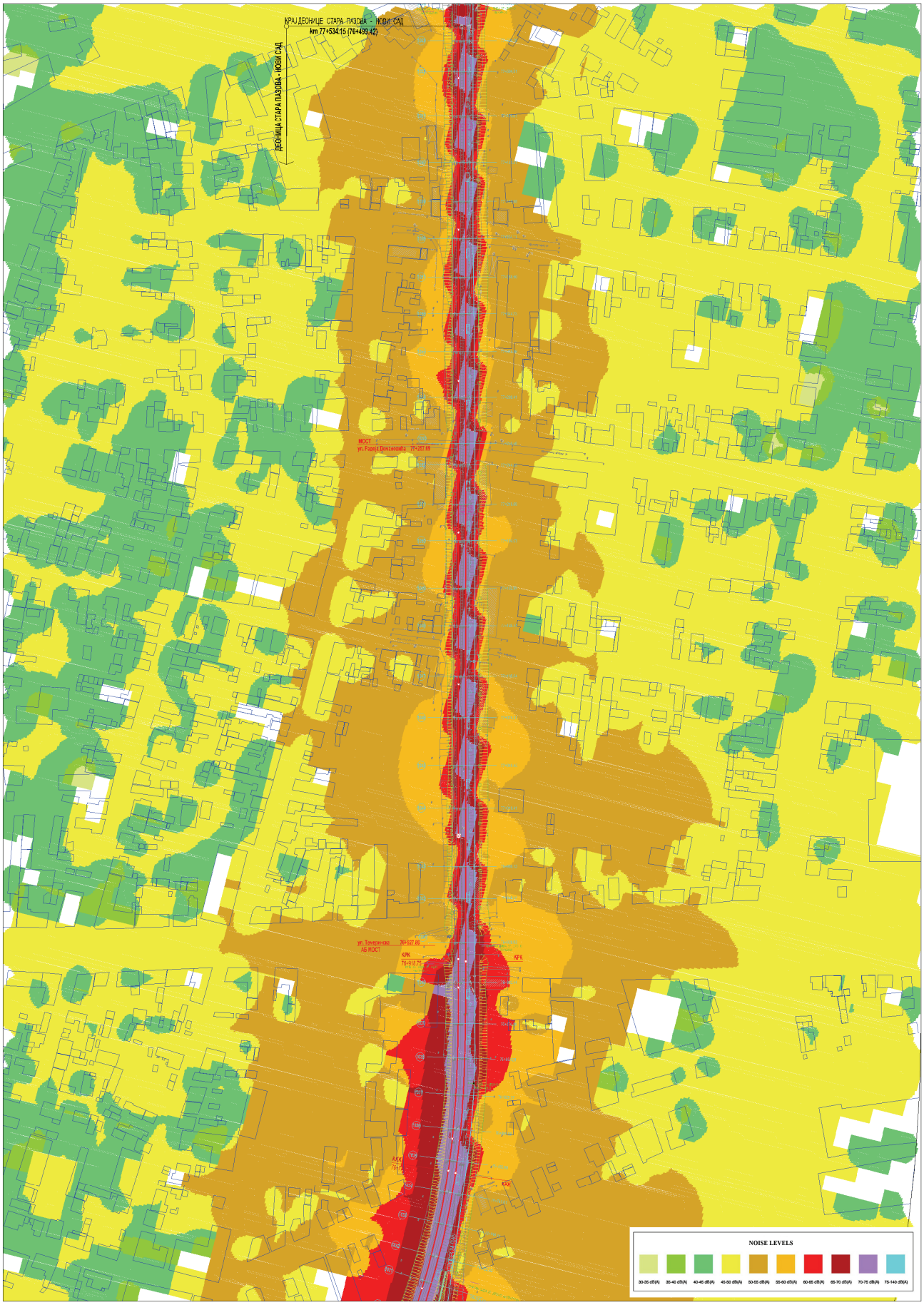


Fig. 2 *Noise map for night period after implementing noise protection measures (detail)*

Calculation of noise indicators was performed at 2.25 of height above ground by applying the first degree reflection during noise propagation. Measuring points for determining noise levels for individual housing structures were positioned at 0.5 m of distance before the facade.

A dynamic error of 0.5 dB(A) has been defined during simulation and calculation of noise level with the „Predictor-LimA Software Suite - Type 7810“ software package.

Calculation of noise indicators was performed with estimated data regarding traffic volume, characteristics of the new railway line and 3D terrain model. Graphic display of estimated noise indicators for night periods, in the form of noise maps are shown in Figure 1.

Estimate of noise annoyance affecting the population of Petrovaradin and Novi Sad was performed according to the LKZ-method. The obtained results, shown in the number of housing facilities exposed to specific ranges of noise indicators during the night, are given in the Table 1.

Table 1 – *Analysis of the exposure of housing facilities before placement of noise barriers exposed to L_{night}*

Noise indicators range L_{night} [dB(A)]	No. of housing facilities exposed to noise indicators ranges L_{night}
< 45	744
45 – 50	766
50 – 55	219
55 – 60	47
60 – 65	7
65 – 70	0
> 70	0

3. NOISE PROTECTION MEASURES

In order to achieve the legally prescribed noise levels on specific facilities, construction of noise barriers is conceived as the basic protection measure.

Minimum height of the noise barriers is 2 meters, while maximum height is limited to 4 meters. On the bridges height of the noise barriers is 2 meters. These barriers are made of absorptive materials.

To ensure the greater efficiency, noise barriers must be placed close to the noise source. In the case of railway minimum distances are calculated from the axis of the track and depend of the position of the noise barriers in regard to the track and the projected speed, and range from 3.30 meters to 4.10 meters.

Noise barriers is designed to protect at least three housing facilities and other sensitive structures in one group. Effectiveness of noise barriers at least one protected object must be greater than 5 dB.

For housing and other structures sensitive to noise, where legal limits are not exceeded for more than 1 dB, protection measures are not envisaged, but noise monitoring plan is engaged.

In the studied zone of railway section, in the territory of Novi Sad, calculation and optimization indicate that 10 noise barriers shall be constructed, in total length of 4,512.0 m, with area of 12,525.0 m^2. Graphic display of the indicators for the night period, after placement of noise barriers, in the form of noise maps are given in Figure 2.

Estimated disturbance to population after placement of the noise barriers, shown as the number of housing structures exposed to specific noise indicator ranges, for the night period, is given in Table 2.

Table 2 – *Analysis of the exposure of housing facilities after placement of noise barriers exposed to L_{night}*

Noise indicators range L_{night} [dB(A)]	No. of housing facilities exposed to noise indicators ranges L_{night}
< 45	1098
45 – 50	619
50 – 55	63
55 – 60	3
60 – 65	0
65 – 70	0
> 70	0

Other methods of protection, such as replacing the existing joinery with soundproof one, shall be applied on structures which are not protected with noise barriers, and on those structures where allowable noise levels are significantly exceeded even with application of noise barriers. Decision on which protection method shall be applied (which type of sealing glass shall be used) shall be made for each particular case, bearing in mind that the aforementioned issues shall not be resolved with inadequate soundproofing, while major soundproofing works shall not be feasible due to high costs. Sound proofing of exterior walls and closed air-conditioning system shall be provided for each building protected by replacing joinery. This approach is inadequate since noise level outside structures and in courtyards is not mitigated.

After commissioning, the railway line shall be monitored in order to determine the exact levels of noise; also occasional measurements shall be undertaken in future to monitor noise levels.

Monitoring noise level during operation aims to foresee and implement protective measures in time. The most efficient technical measures for noise protection can only be envisaged after taking a series of measurements during operation of this railway section over a longer period of time. This is due to the fact that data regarding noise level at one moment and one location do not represent the overall noise level for that location, nor the noise in the specific communal environment. Besides, other sources of noise also have influence on the selection of protective measures, as well as the very structure of the building located in the impact zone, since if partial solutions are applied, counterproductive effects may occur (reflection, superposition etc.).

Measuring points are selected so that they are typical for the studied area. In case of justified complaints from local population, number of measuring points may be increased.

4. CONCLUSIONS

Environmental planning is the basic instrument of a society for coordinating social development with due consideration given to the environmental, social and economic factors.

The (Beograd) - Stara Pazova - Novi Sad - Subotica - Hungarian border railway line, section Stara Pazova - Novi Sad represents an existing infrastructural unit with significant effect on the environment. In terms of noise, increase of speed and volume of traffic bears negative effect on the environment, while renewal and improvement of the existing track bears positive effect. It must be taken into consideration that during designing and construction of this railway, environmental issues were not dealt with in accordance with relevant legal regulations.

Planning of noise protection measures must be carried out with consideration to optimization. In Serbian legal and other regulations there are no clearly defined guidelines for optimization, so the designer's experience and understanding are the key instruments.

For protection of residential and other buildings in the territories of Petrovaradin and Novi Sad, 10 noise barriers are required. As an additional protective measure, replacement of the existing joinery with new, soundproof one is conceived. Sound proofing of exterior walls and closed air-conditioning system shall be provided as well.

In order to provide constant protection against noise, monitoring of noise levels shall be established.

All of the incorporated infrastructural units shall be maintained in good working order, in accordance with recommended procedures and relevant railway rulebooks and instructions.

REFERENCES

[1] "Idejni projekat rekonstrukcije, modernizacije i izgradnje dvokolosečne pruge Beograd-Novi Sad-Subotica-granica Mađarske, deonica Stara Pazova-Novi Sad", Saobraćajni institut CIP, Beograd, 2010.

[2] "Elaborat konačna procena uticaja projekta rekonstrukcije i modernizacije železničkih pruga na životnu sredinu, kao dela konačnog izveštaja projekta obnove železnice I (Prilog 9 izveštaja za Svetsku banku)", Saobraćajni institut CIP, Beograd, 2007.

[3] "Plan detaljne regulacije rekonstrukcije, modernizacije i izgradnje dvokolosečne pruge Beograd-Novi Sad-Subotica-granica Mađarske, deonica Stara Pazova-Novi Sad, na području grada Novog Sada - Izveštaj o strateškoj proceni uticaja na životnu sredinu", Saobraćajni institut CIP, Beograd, 2011.

[4] N.J. Craven, G. Kerry, "A Good Practice Guide on the Sources and Magnitude of Uncertainty Arising in the Practical Measurement of Environmental Noise", University of Salford, Manchester, 2007.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

MORPHOLOGY OF MODULAR TRAFFIC NOISE BARRIERS

Vladan Grković[1], Milan Kolarević[1], Zvonko Petrović[1], Miomir Vukićević[1]

[1] University of Kragujevac, Faculty of Mechanical Engineering Kraljevo, Serbia, grkovic.v@mfkv.kg.ac.rs

Abstract - *The paper presents the morphology of the existing solutions of modular noise barriers with detailed classifications and description of shapes of the main modules and their structures. The advantages of the modular approach and the specific characteristics which refer to integration of barriers into the topography and their visual integration into the environment for the purpose of accomplishing a positive aesthetic effect are particularly emphasized.*

Key words: *noise barrier, modular, morphology.*

1. INTRODUCTION

The dominant source of community noise is traffic (road, rail and air). The level of noise produced by means of transportation in the environment ranges within 70÷110 dB(A). Road traffic noise is the most common source of noise in all countries. It depends on [1]:

- the speed of vehicles
- the structure of the traffic flow
- the form of the surface
- terrain configuration
- meteorological conditions, and
- background noise.

Noise control can be carried out:

- at the noise source
- along the noise propagation paths
- at the receiver.

Manufacturers of road vehicles constantly make efforts to reduce the noise produced by the driving unit and pneumatics in contact with the base. However, it is not enough and that is why it is often necessary to apply the measures of noise control in road transport along the noise transmission paths from the source to the receiver, i.e. the object affected by noise. The level of noise along the propagation paths is reduced by applying:

- barriers (obstacles)
- tunnels
- natural obstacles (earth mounds), and
- a combination of the mentioned ways.

Noise barriers (acoustic screens) reduce noise to a satisfactory level by preventing the propagation of noise waves. Practical mitigation of the level of noise with the application of reflecting barriers ranges within 10-15 dB(A), and the application of absorbing barriers can improve this efficiency by additional 5 dB(A).

Classification of shapes and structures of modular noise barriers is presented in the continuation.

2. MORPHOLOGY OF MODULAR NOISE BARRIERS

2.1 Barrier morphology

Barrier morphology is *classification of the form and structures* relating to barriers. Essentially, barrier morphology is uncomplicated, as barriers are made up of a small number of essential parts. Barriers can be made either of one part or several modules. Even in one-part barriers three main sections can be noticed: a base section, a middle section and a top section.

Modular types of barriers are most frequently used. Modular construction of barriers is a system of construction of industrially made elements, which are assembled *in situ*. Individual modules (barrier wall, support structure and end profiles), except the foundation, are entirely manufactured in a factory, then they are transported to the site where they are assembled into a barrier.

The use of a modular structure results in a product which is composed of modules that are possible to replace and whose geometrical values or functions can be changed for the purpose of obtaining a sufficient number of different variants.

The main modules of a barrier can be:

1. Foundation
2. Barrier wall
3. End profiles
4. Support structure
5. Top edge

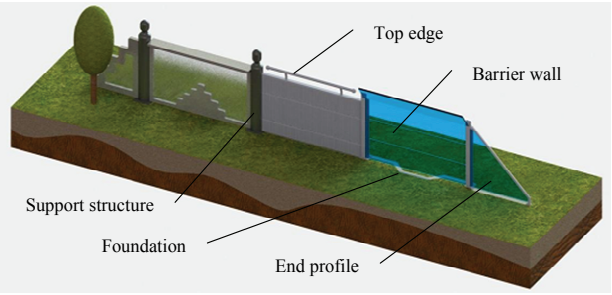


Fig. 1 *Barrier morphology*

In the process of barrier design, it is necessary to take into account the shape of its profile. It can be vertical, angled, partly concave or cantilevered. The barrier profile angle does not only affect the direction of noise reflection, but it also has some important aesthetic effects.

The barrier has two façades: the front one, i.e. the side which faces the traffic and the back one, which faces the protected

area. There is a frequent requirement that the front and rear façades should be different. This difference is realized by a combination with planting, with the application of different materials, etc. The requirement for reduction of the noise level usually refers to only one façade of the noise barrier.

In the process of barrier design, it is also necessary to consider *the topography of the terrain*, i.e. rises and falls, earth mounds, etc.

2.2 Foundation

Foundation is one of the main modules of noise barriers whose aim is to transmit the entire load from the facility to the load-bearing ground without harmful stresses and deformations in the soil. It is one of the most important parts of the barrier because the stability and durability of the barrier depend on it. For proper design and construction of the foundation, it is necessary to know the barrier loads and have detailed knowledge of the soil, i.e. the composition of the terrain, its layers, physical properties, etc.

The foundation depth is a vertical distance from the ground surface to the contact surface between the foundation and the soil. According to the foundation depth, there are: shallow foundations and deep foundations. *Shallow foundations* are usually made at the depth of about one meter (at the depth up to which the ground freezes in frost-prone regions, i.e. at the depth at which there is the first stable layer of the ground). There are different shapes of shallow foundations: strip foundation, isolated foundations, foundation plates, grillage foundation.

Deep foundations are applied for supporting facilities on a deeper soil layer (or a rock), which has better physical-mechanical characteristics than the upper (surface) layer. There are different types of deep foundations, such as: piles, caissons, wells. Foundation is the only module that is always made *in situ*. According to the foundation shape, there are the following types:

2.2.1 Classical strip foundation

This way of support is applied when loads are small. The foundation is directly ground-supported, without extension (the footing) and with such a depth in the ground that is sufficient for the stability of the structure and safety against frost. Anchors to which the support posts are fixed are cast in the concrete foundation. The barriers with the height from 2 to 2.5 m are predominantly installed to this type of foundation.



Fig. 2 *Classical strip foundation*

2.2.2 Strip foundation with the footing

If there are heavy loads, which should be transmitted to larger surfaces so that ground loading would be within the allowed limits, reinforced concrete foundations with the footing are constructed. They are very economical for the case when there are strong winds and where the soil has small load-bearing capacity. The barriers with the height from 2 to 3.5 m are installed to this type of foundation through support posts which are fastened to the foundation by means of anchor bolts.

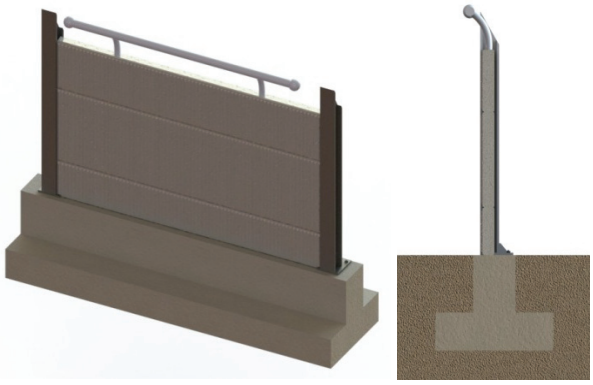


Fig. 3 *Strip foundation with the footing*

2.2.3 Zig-zag foundation

Zig-zag foundations are predominantly of a trapezoid shape, but they can also have an alternative curved shape. In the case when the weight load is small and when the soil has a satisfactory load-bearing capacity, at the places where there are strong winds, it is more rational to construct this type of foundation than the strip foundation with the footing. The barriers with the height from 2.5 to 3 m are predominantly installed to this type of foundation. The posts that carry the panels which form the noise barrier are anchored to the foundation.

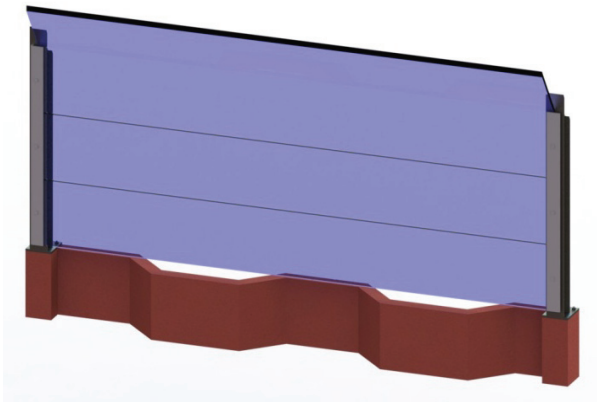


Fig. 4 *Zig-zag foundation*

2.2.4 Foundation with footings

They are foundations with isolated concrete footings (isolated foundations) into which the posts are placed. The footings can be with or without extension depending on the type of terrain. It is desirable, for the purpose of the footing structure stability, to connect them by concrete beams. The barriers with the height from 3 to 5 m are predominantly installed to this type of foundation.

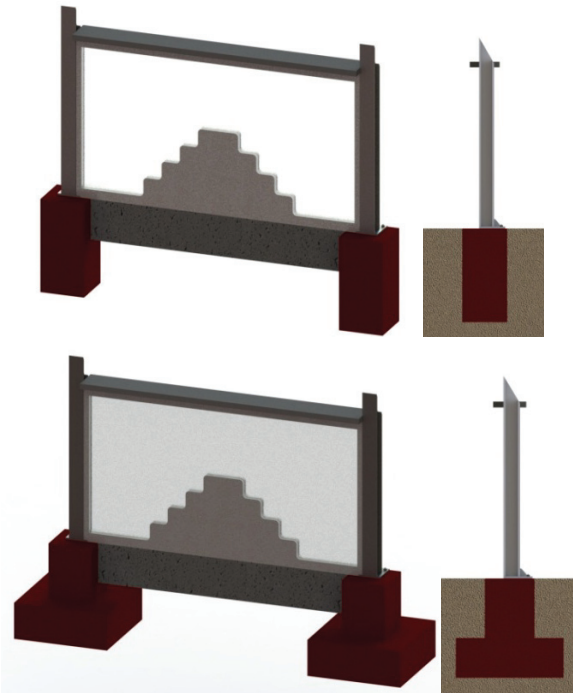


Fig. 5 *Foundation with footings*

2.2.5 Foundation connected with the bottom section

This is the type of concrete foundations which is partly in the ground, and partly above the ground. The part above the ground represents the bottom section of the barrier, it is cast together with the foundation *in situ* and can be up to 1.5 m high. They are predominantly used at high embankments, higher than 3 m, where winds are medium. The bottom section actually replaces the base section of the noise barrier and most often serves as protection from traffic. The total height of the barrier wall and the bottom section is up to a maximum of 3m.

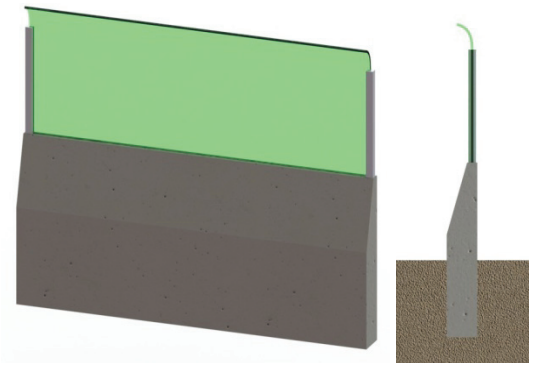


Fig. 6 *Foundation connected with the bottom section*

2.3 Barrier wall

The barrier wall is the major and largest module of a noise barrier. It performs the main role of the barrier, which means that it reduces the excessive noise to a satisfactory level by reflection, absorption or diffraction.

In this module three units can be noticed:

- lower part (base section)
- medium part (middle section)
- upper part (top section)

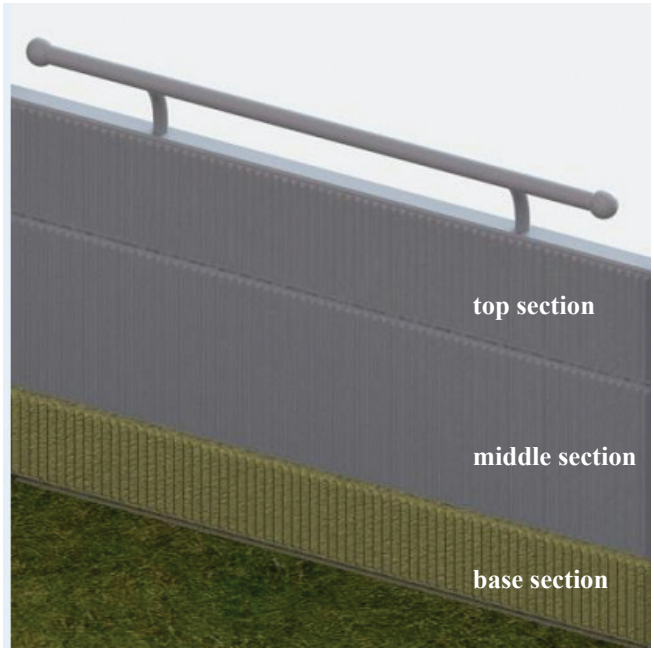


Fig. 7 *Barrier wall*

The barrier wall is rarely made out of one part, and it is often the case that certain sections are assembled of several panels of the same or different type.

2.3.1 Bottom section

The bottom section of the barrier wall may in reality be obscured by planting, grass or perhaps a kerb or safety fence. Planting reduces pollution from car exhaustion gases and provide the barrier with a good visual effect and better integration into the environment. This section is sometimes cast of concrete *in situ*, together with the foundation. The holes for necessary drainage of collected water and passing of small animals are most often left between the bottom edge and foundation. During the design, it is necessary to make sure that the bottom section should be in an appropriate proportion to the sections of barrier above.

2.3.2 Middle section

The middle section (barrier body) is likely to form the largest visually apparent part of the barrier. Ideally, to avoid visual clutter and disharmony, the middle section of the barrier should only comprise a single material with the possibility of changing its form and colour.

2.3.3 Top section

In rural areas, it is desirable that the barriers should be concealed by vegetation or appear transparent so that they could be integrated into the landscape. The top section is most often made of transparent materials so that the barrier could blend into the backdrop of the sky or vegetation background.

This can also be the case in urban areas in which a lot of barriers use transparent or lighter materials at the top to reduce the overall apparent height of the barrier and allow light to pass through.

2.4 Top edge of the barrier

Most barriers have a simple or unobtrusive top edge. Designs sometimes allow themselves to design special forms of top edges for the purpose of improving aesthetic appearance of the barrier.

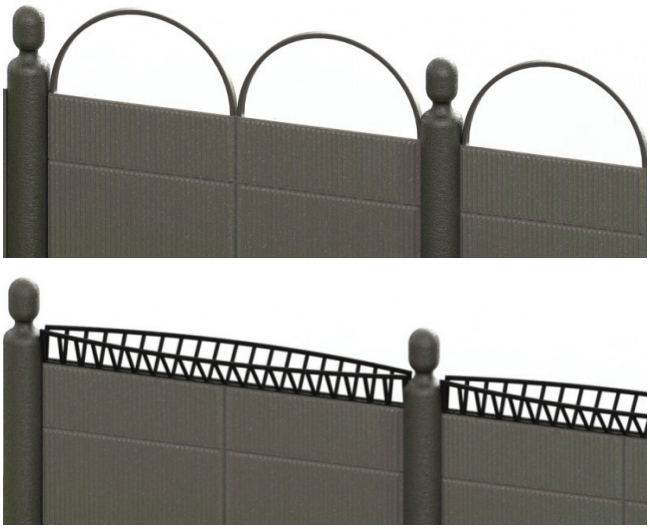


Fig. 8 *Top edge as a decorative element*

Research has shown that special forms of top edges, such as: T-profile, Y-profile, arrow profile, etc. create the diffraction effect and thus reduce the noise level. In addition to diffracting elements, pipe-like absorbers with the cross section in the form of a ball or pear can also be mounted at the top. Application of special forms of top edges additionally reduces noise by 1÷2.5 dB(A), which enables reduction in the barrier height. Lower barriers reduce the level of concealing the environment, which can improve the aesthetic influence on the community and drivers.

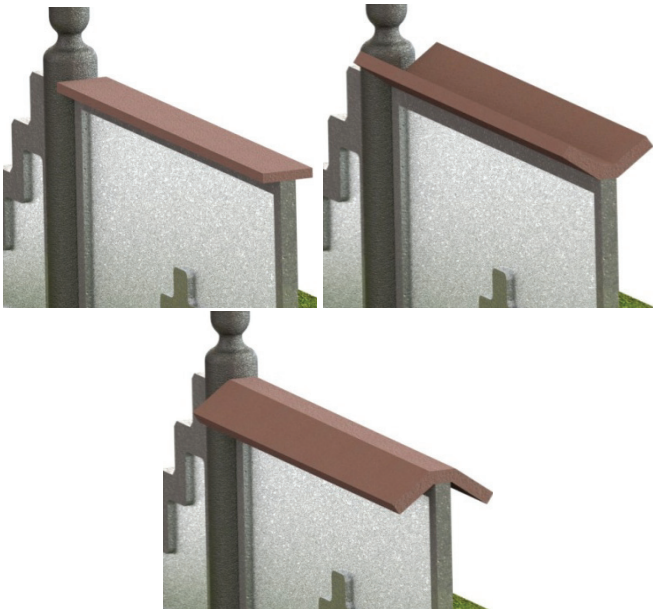


Fig. 9 *Diffracting forms of top edges*

Although special top edges have certain acoustic and aesthetic advantages, the costs of their manufacture usually exceed the costs of manufacture of higher barriers with the classical form of top edge which have the same acoustic effect, so that there are trends to eliminate top edges from use.

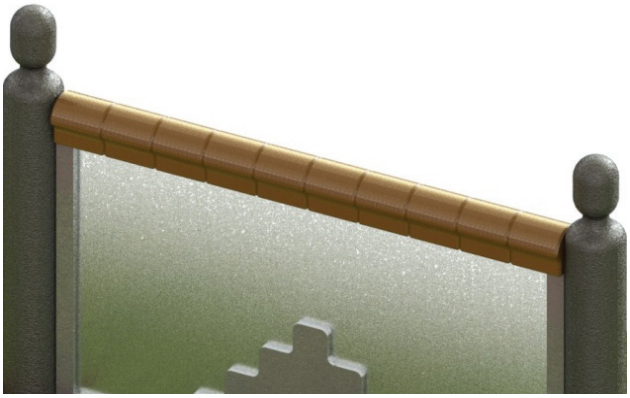


Fig. 10 *Absorbing forms of top edges*

2.5 End profiles

The end profile of the barrier is usually placed as an “add on” to the full length and height of the main barrier and it is essentially more of an aesthetic detail than an acoustically functional element. The task of the end profile is to provide a gradual visual transition, instead of an abrupt one, from a space concealed by the barrier to an open space without the barrier.

In barriers located in an urban zone, the abrupt ending of the barrier is frequently visually acceptable. An appropriate appearance may be achieved by the use of a characteristic profile, which integrates well with the overall barrier design. If it is necessary to disguise the barrier ends, then it is most simple to envelop it in planting, but it would be visually more pleasing to have planting along the barrier on both sides. However, most barriers tend to taper, step up or break up when they start or finish, and sometimes specific shapes are used.

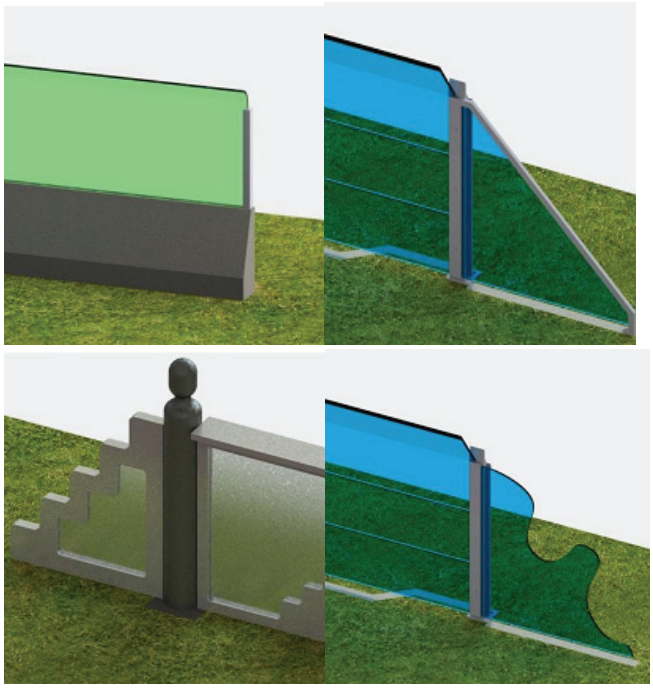


Fig. 11 *Shapes of barrier ends*

2.6 Support structure

The barrier can be subjected to significant loading, especially wind loading, and must be designed to satisfy certain conditions. This function is assumed by the support structure which can be visible or concealed within the façade.

Most barriers are formed from noise panels, which are directly positioned between vertical posts. In modular barriers, the support posts are frequently bolted onto the concrete base – foundation. In large spans, where the number of support posts is small, it is often necessary to provide lateral support structures to the panels, which is usually placed from the rear side. If barriers are smaller by their overall dimensions, precast panels can be bolted directly onto the foundation, and the use of support posts is thus avoided.

As with any other architectural forms, the support structure of a barrier may be used as a functional as well as an aesthetic element. The structure may then have an important visual function, which contributes to its integration or non-integration in the surrounding landscape.

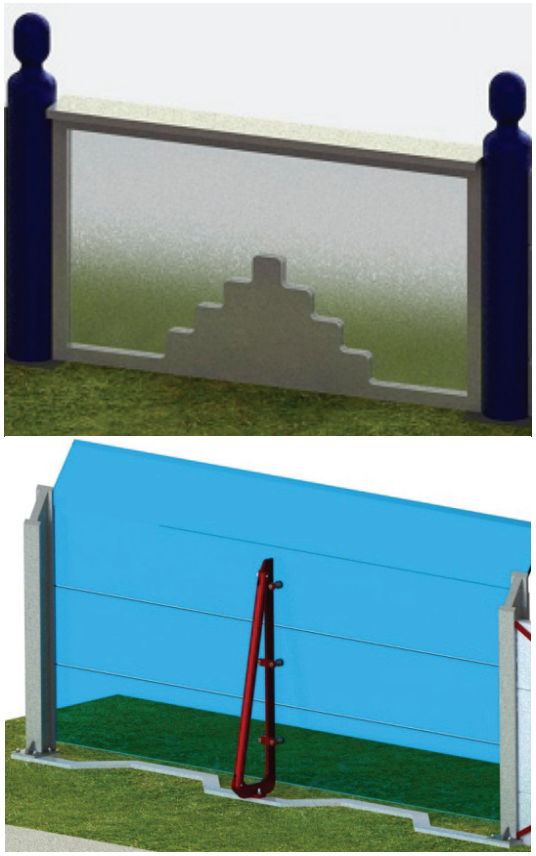


Fig. 12 *Support structure of a barrier*

An important barrier module, especially from cost, weathering and maintenance considerations, are fixings. They should allow the barrier to be fitted into place and allow for the easy removal and replacement of damaged panels or modules. At the same time, this is the most important advantage of a modular structure because in case of damage of certain modules of the barrier it will be faster and cheaper to replace the module than repair it. The barrier appearance remains the same as before the damage.

Fixings are mostly simple components. They are bolt joints between the posts and the foundation, grooves in which noise panels are inserted and similar fixing elements that provide easy mounting and disassembling of certain modules. More complex fixings sometimes appear only in the top section of the barrier when it is necessary to provide the connection between the top parts of the barrier which have a decorative or functional character.

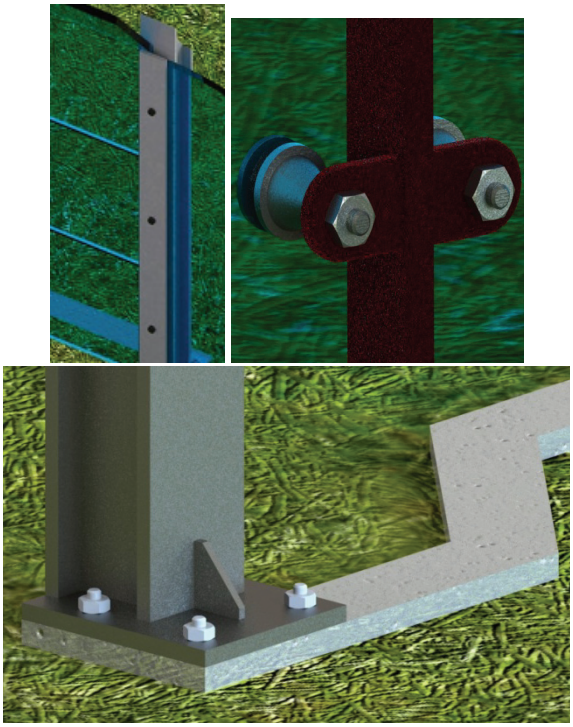


Fig. 13 *Fixings of the barrier*

3. CONCLUSION

Design of means for active and passive noise protection was planned within the project TP37020 – "Development of methodologies and means of noise protection in urban areas" (UrbaNoise). In addition to development of methodologies and means of active noise protection, a considerable part of the project activities was devoted to design, construction and testing of means of passive noise *protection*, such as modular noise barriers and noise absorbers intended for different conditions of use and application.

Taking into account the trends of approaching the European Union, our country has assumed the obligation to harmonize the domestic legislation with the EU legislation. In the field of noise protection and in compliance with the Directive 2002/49/EC of the European Parliament and the Council of the European Union, Serbia has made a series of laws and bylaws. The next phase will be the obligation to monitor noise in settlements and along the main roads, to establish endangered zones and measures for reduction of noise in them as well as quiet zones and measures for their preservation.

One of the ways to reduce noise along the main roads is construction of noise barriers. Since in our country there are no companies that deal with this problem, this project is important because it represents a manner of developing means of adequate noise protection and offering them to companies as a new production programme. It is an opportunity to employ domestic industrial capacities and save considerable amounts of money because the price of a noise barrier in the European Community, depending on its characteristics, size, etc. is around 1.000.000 € per kilometer.

Acknowledgement: The paper is a part of the research done within the project TR37020. The authors would like to thank to the Ministry of Education and Science of the Republic of Serbia for supporting this research.

REFERENCES

[1] M. Praščević, D. Cvetković: *Environmental Noise*, Unive-rsity of Niš, Fakultet zaštite na radu, Niš, 2005.

[2] B. Kotzen, C. English: *Environmental Noise Barriers , A guide to their acoustic and visual design*, Second edition, Taylor & Francis e-Library, London and New York, 2009.

[3] G. G. Fleming, H.S. Knauer, Cynthia S.Y. Lee, S. Pedersen: *Noise Barrier Design Handbook, Highway Traffic Noise*, http://www.fhwa.dot.gov/environment/noise/noise_barriers/design_construction/design/index.cfm

[4] M. Kolarević, Z. Šoškić, Z. Petrović, B. Radičević: *Noise Protection In Urban Environment- Description Of A Project*, Mechanics, Transport, Communications, Academic journal, Todor Kableshkov University of Transport,Sofia, ISSN 1312-3823, issue 3/2011, pp.IV-69-IV-78.

[5] R.E. Klingner, M.T. McNerney, Ilene Busch-Vishniac: *Design Guide For Highway Noise Barriers*, Research Report 0-1471-4 , Center for Transportation Research The Unive-rsity of Texas at Austin, November 2003

[6] H. Knauer, S. Pedersen: *FHWA Highway Construction Noise Handbook*, Highway Traffic Noise, **Error! Hyperlink reference not valid.**

[7] R.F. Blum: *A Guide to Visual Quality in Noise Barrier Design*, Highway Traffic Noise, http://www.fhwa.dot.gov/environment/noise/noise_barriers/design_construction/visql/acknowledge.cfm

[8] *Guidelines on Design of Noise Barriers*, Environmental Protection Department and Highways Department Government of the Hong Kong SAR, Second Issue, January 2003

[9] *Cutting down noise with precast concrete and masonry barriers,* British Precast, 2005, http://www.britishprecast.org/documents/CuttingDownNoise.pdf

[10] *B. Berglund, T. Lindvall, D. H. Schwela (editors): Guidelines for community noise. WHO. World Health Organization 1999.* www.who.int/docstore/peh/noise/guidelines2.html

[11] A. Zlatković, *Analysis of railway vehicles noise management,* Master thesis, Faculty of Traffic Engineering, Belgrade, 2010.

[12] *Design Guide For Environmental Barrier,* Volume 10 Section 5, Part 1 HA 65/94, 2001

[13] *Environmental Barriers: Technical Requirements,* Volume 10 Section 5, Part 2 HA 66/95, 2001.

[14] *Highway Traffic Noise Analysis And Abatement Policy And Guidance* by U.S. Department of Transportation, Federal Highway Administration, Office of Environment and Planning Noise and Air Quality Branch, Washington, D.C., June 1995

[15] *Directive 2002/49/EC* of The European Parliament and The Council of The European Union

[16] *Serbian standard ISO 1996-1,2*, Official Gazette of Republic of Serbia,

[17] [17] *Law on environmental noise protection of Republic of Serbia*, Official Gazette of Republic of Serbia, No. 36/2009

[18] *Regulation on noise indicators, limiting values and methods for estimation of noise indicators, annoyance and detrimental effects of noise*, Official Gazette of Republic of Serbia, No. 75/2010

[19] *National strategy of sustainable development*, Government of Republic of Serbia, Belgrade 2008

[20] http://www.silence-ip.org

[21] http://www.imagine-project.org

[22] http://www.mfkv.rs/urbaNoise

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

CONFIGURATION OF MODULAR NOISE BARRIERS

Milan Kolarević[1], Vladan Grković[1],Miomir Vukićević[1], Mišo Bjelić[1]

[1] University of Kragujevac, Faculty of Mechanical Engineering Kraljevo, Serbia, kolarevic.m@mfkv.kg.ac.rs

Abstract - *The preliminary design of modular traffic noise barriers was elaborated within the project TP3702 "Development of methodologies and means of noise protection in urban areas". The paper presents the process of configuring modular barriers, the platform which serves as a base and the fund of available modules. Variations in solutions of noise barriers, such as: variations of size and shape of barriers, variations due to the change of barrier orientation, variations due to terrain configuration as well as the combination of barriers with planting, decorative elements, etc. are particularly emphasized.*

Key words: *configuration, noise barriers, modular type, variations*

1. INTRODUCTION

The National Sustainable Development Strategy [20] adopted in 2008 recognizes that noise is a problem in settled areas in the Republic of Serbia and that it is a risk to population health. It points out all types of traffic and various industrial plants as the main causes of noise in the living environment. The main problems stressed by the National Strategy are:

- the lack of coordination with the EU regulations,
- the non-existence of modern regulations for noise measurement,
- the non-existence of regular noise-level monitoring, except in some large cities,
- the non-existence of plans at any level for solving noise issues,
- the lack of compliance with noise insulation regulations in civil engineering, etc.

The Law on Noise Protection, the Regulation on Noise Pollution Indicators and a series of *Rulebooks and Standards* have been adopted in accordance with the strategy and for the purpose of coordinating the national regulations in the field of noise with the EU legislation.

The dominant source of community noise is road traffic. The noise level produced by road vehicles ranges within 60-90 dB(A) depending on the type and speed of vehicles (Figure 1).

The efforts made by car manufacturers to reduce the noise produced by the driving unit and pneumatics in contact with the base are not enough and therefore it is necessary to use noise barriers in settled areas in order to reduce noise to a satisfactory level.

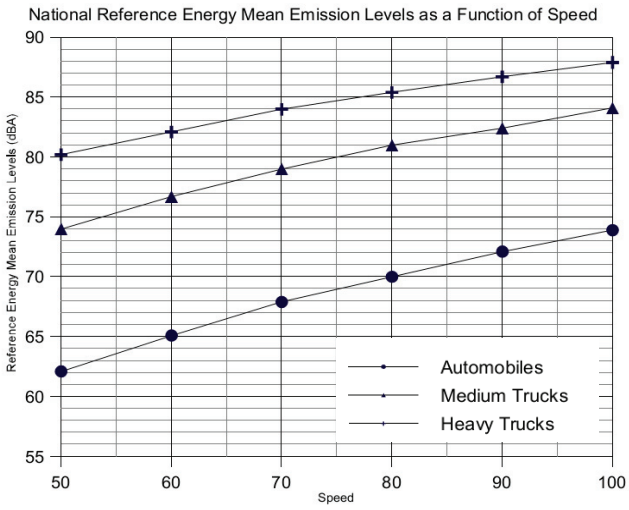


Fig. 1. *Dependence of the traffic noise level on the type and speed of vehicles* [15]

The preliminary design of modular traffic noise barriers was elaborated within the project TP3702 "Development of methodologies and means of noise protection in urban areas". The continuation of the paper presents the process of configuring modular barriers, the platform which serves as a base and the fund of available modules and submodules. Variations in solutions of noise barriers, such as: variations of size and shape of barriers, variations due to the change of barrier orientation, variations due to terrain configuration as well as the combination of barriers with planting, decorative elements, etc. are particularly emphasized.

2. MAIN PRINCIPLES OF NOISE BARRIER DESIGN

2.1 Requirements which should be satisfied in the barrier design process

Noise barrier design is a process which consists of a certain number of logical phases and has the task to achieve the agreed targets. The primary goal is certainly reduction of too much noise by the roads. This acoustic requirement refers to:

- reduction in the noise level at the receiver (outside the road)
- mitigation of the noise level at the noise source (on the road itself).

However, in order to accomplish successful noise barrier design, it is necessary to consider a multitude of other non-acoustic aspects, such as:

- visual attraction (aesthetic appearance),
- compatibility with the local environment,
- safety of drivers in terms of: reduced sight distance, light reflection, safety of a vehicle in collision with a barrier, etc.
- safety of animals living in the habitat where barriers are installed (visible to birds, holes so that smaller animals may pass through, etc.),
- ecological (preservation of animal habitats and local hydrology, toxicity of barrier materials, etc.),
- barrier loading (self-weight, wind gusts, snow, vibrations due to traffic, etc.),
- configuration and structure of the terrain,
- producibility of manufacture and mounting,
- easy maintenance (fast and easy replacement of modules, possibility of cleaning, access to the barrier, etc.),
- costs of manufacture, mounting and maintenance,
- product life (protection from vehicle impact, resistance to chemical influences, resistance to frost, fire, UV radiation, humidity, etc.),
- possibility of recycling after the expiration of the period of utilisation, etc.

A successful noise reduction system can be realized only by applying a multidisciplinary approach in the design process. In order to achieve the project goals, it is necessary to coordinate the work of mechanical and civil engineers, traffic engineers, acoustic engineers, architects, etc. The results should be the noise barriers which fit in the existing environment so that they could be accepted by the local community.

2.2 Modular structuring of products

The use of a modular structure results in a product which is composed of modules that are possible to replace and whose geometrical values or functions can be changed for the purpose of obtaining a sufficient number of different variants. The advantages of application of a modular structure in the process of product design and manufacture, both for the manufacturer and the user, are as follows [3]:

- a large number of product variants realized by a combination of modules,
- the possibility of module replacement,
- a lower price of product variants by using the advantage of serial production of individual modules,
- shortened time for launching a product on the market,
- simplified maintenance,
- possible disassembling of the product at the end of its life cycle.

Modular construction of barriers is a system of construction by means of industrially manufactured elements that are assembled *in situ*. Individual modules (barrier wall, support structure and end profiles) are completely manufactured in the factory, they are then transported to the site where they are assembled into a barrier.

The main modules of a barrier can be:

1. Foundation
2. Barrier wall
3. End profiles
4. Support structure
5. Barrier top

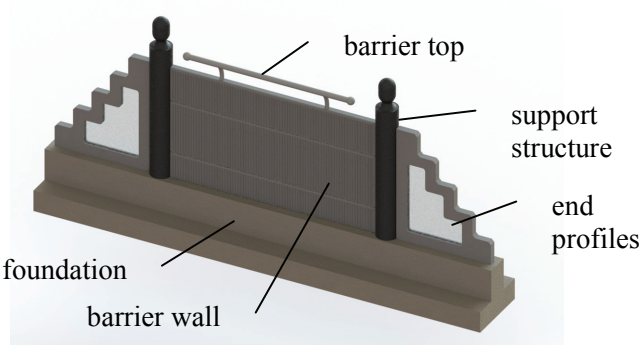


Fig. 2 *Main modules of a traffic noise barrier*

2.3 The product platform and the product family

The product platform represents a set of guidelines that allow a company to develop a sufficient number of product variants aiming at satisfying its customers' needs. The product platform covers [3]:

- a set of main physical components, i.e. modules,
- a set of rules and relations by means of which it is possible to combine product variants,
- a set of available technological possibilities which can be applied in the domain of production,
- a set of employees and their relationships – teams, mutual relationships within the team members and relationships between the teams themselves,
- a set of skills – design knowledge, technology, mathematical models and testing methods, etc.

Product variants offered by a company to the market for the purpose of satisfying individual needs of customers, which is accomplished with the application of a modular structure and the product platform, represent **a product family.** The relation between the modular structure, the product platform and the product family is presented in Figure 3.

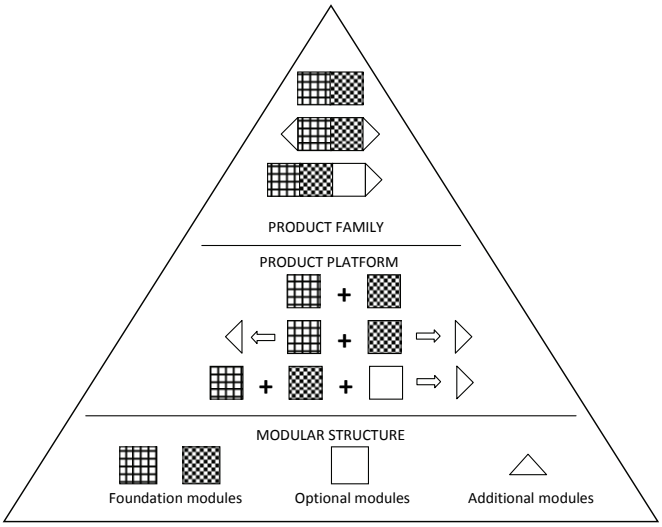


Fig. 3 – *Relation between the modular structure, the product platform and the product family* [3]

3. CONFIGURATION OF MODULAR NOISE BARRIERS

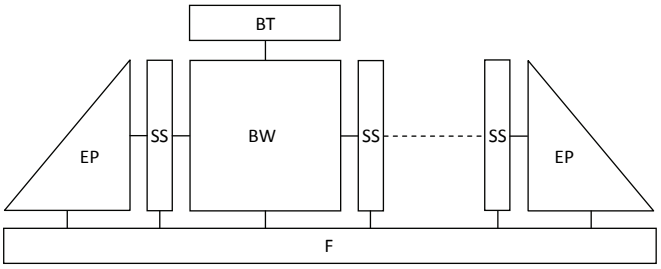
The life of modern products is increasingly shorter, products are more complex, there is a requirement for an increasingly large number of product variants and the shorter total time necessary for launching a product on the market. In addition, the pressure both by the customers and the competition is increased, so that nowadays there are product variants on the market that are more adapted to individual requirements of customers. In order to have a competitive modern company on the market, it is necessary for it to be capable of developing products, within a short period of time, that fulfil the requirements of individual customers. The problem of adapting products to the requirements of customers is solved by developing *configurable products*.

The process of configuring products is an activity that allows determination of the structure of a product variant - out of an available set of modules - which is adapted to the requirements of the customer but still respecting the rules and restrictions set by the product structure.

The result of a configuration process is not always only one configuration because there can be several of them. A configuration process is also an iterative procedure so that it is often necessary to repeat the process several times until the configuration which entirely satisfies all the requirements is obtained. Depending on the requirements, a configuration process can but does not have to find the appropriate configuration, i.e. it may happen that no configuration satisfies the requirements.

The process of forming (configuring) a modular noise barrier (Figure 4) is as follows:

- the foundation which is cast in situ is formed first,
- the support posts are then fixed to the foundation,
- the panels which form the barrier wall are inserted between the support posts,
- the barrier top is fixed to the barrier wall if it is foreseen by the requirement,
- if necessary, the end profiles are placed at the beginning and at the end of the protective field,
- with large spans, it is often necessary to add supports.



Legend: F – foundation
EP – end profile
SS – support structure
BW – barrier wall
BT – barrier top

Fig. 4 – *Scheme of the procedure of configuring a modular noise barrier*

The available fund of modules used for configuration of noise barriers is presented in Figure 5.

4. VARIATIONS IN THE CONFIGURATION PROCESS

Depending on the acoustic and non-acoustic requirements and the configuration of the terrain where noise barriers should be installed, the process of configuring a noise barrier should provide a multitude of different variants and combinations which are presented in continuation.

4.1 Variations of the angle and shape of the barrier profile

Acoustic requirements, requirements with respect to sight distance, specific loads which the barrier is exposed to, etc. often require different shapes of profiles that are realized by a combination of the fund of modules of the support structure and the fund of modules which form the barrier wall (Fig. 6).

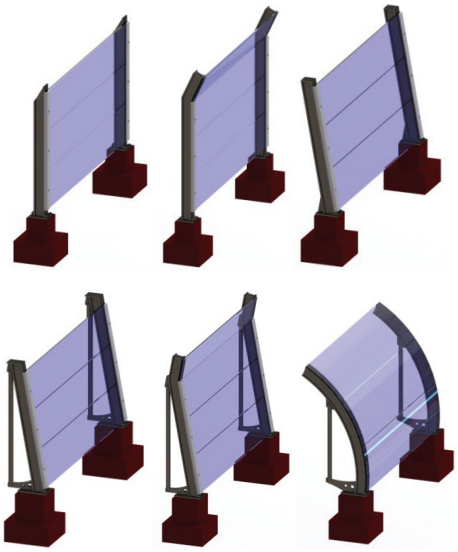


Fig. 6 – *Variations of the angle and shape of the barrier profile*

4.2 Variations of the shape of the support structure depending on the barrier height

Depending on the shape of the barrier profile and its height, especially in the conditions when the barrier is exposed to specific loading such as strong gusts of wind, it is necessary to have an available fund of modules of the support structure that will satisfy these conditions.

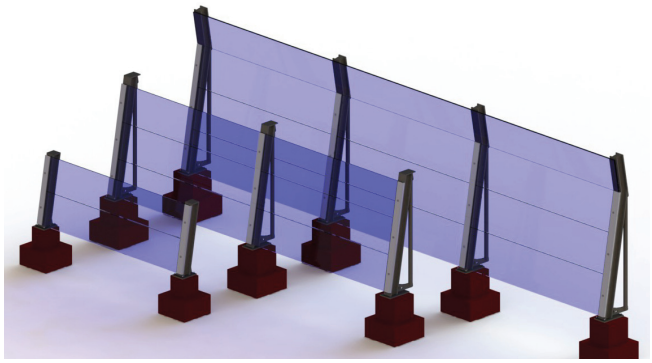


Fig. 7 – *Variations of the shape of the support structure depending on the barrier height*

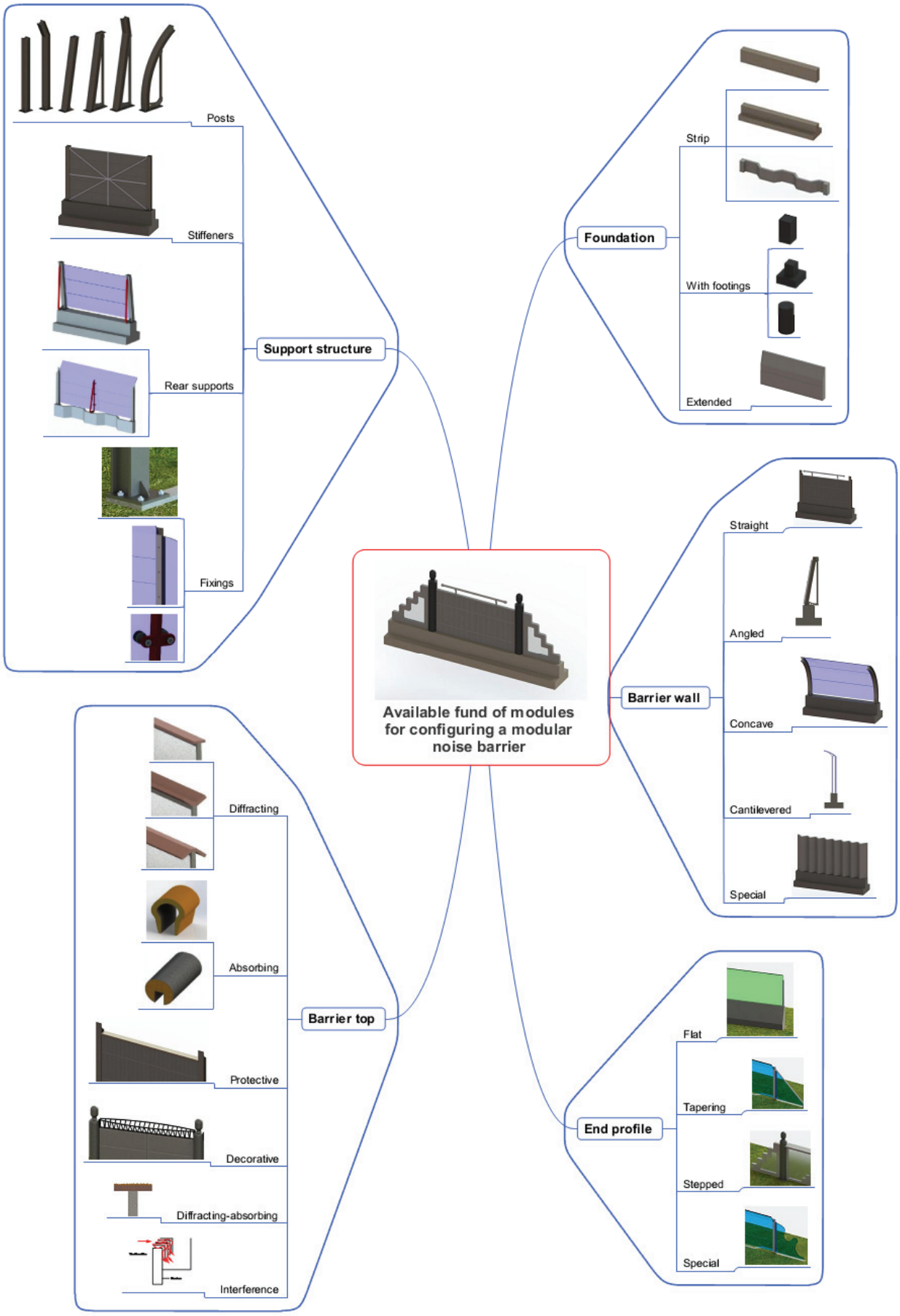


Fig 5 *Available fund of modules for configuring a modular noise barrier*

4.3 Variations due to the change of noise barrier orientation

In suburban areas, in order to accomplish a visual relation between the community and the barrier, it is necessary to integrate barriers into the existing natural environment. Therefore, barriers in these areas are not rectilinear, in a line; their orientation changes and combines with various planting. In that case, it is necessary to have an available fund of different shapes of support posts that can satisfy this requirement.

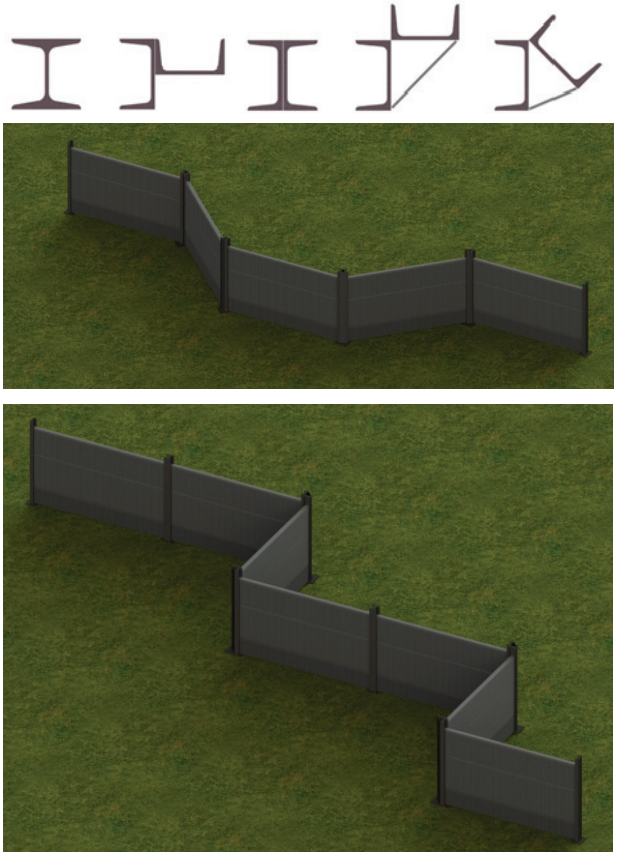


Fig. 8 – *Variations due to the change of noise barrier orientation*

4.4 Variations due to terrain configuration

The terrain where barriers are placed most frequently consists of a lot of rises and falls. If terrain slopes are not steep, this condition can be fulfilled by varying the dimensions of the support posts, i.e. the support structure. If slopes are steep, it is also necessary to have a fund of special modules for creating the barrier wall which do not have a rectangular shape.

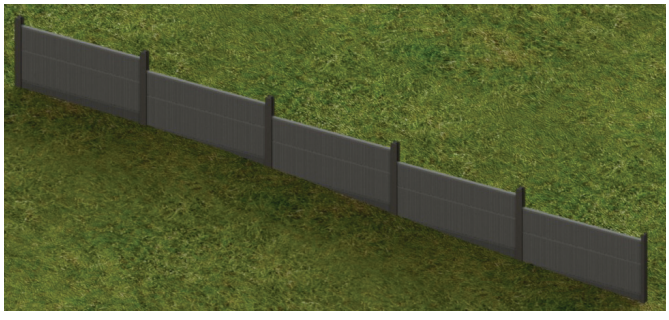


Fig. 9 – *Variations due to terrain configuration*

4.5 Combination of different types of panels for creation of a noise barrier

Different types of panels for the barrier wall are most often combined for the purpose of integration of a barrier in the surroundings and its visual attraction. In order to increase the visibility, i.e. sight distance, transparent and non-transparent panels are frequently combined (Figure 9).

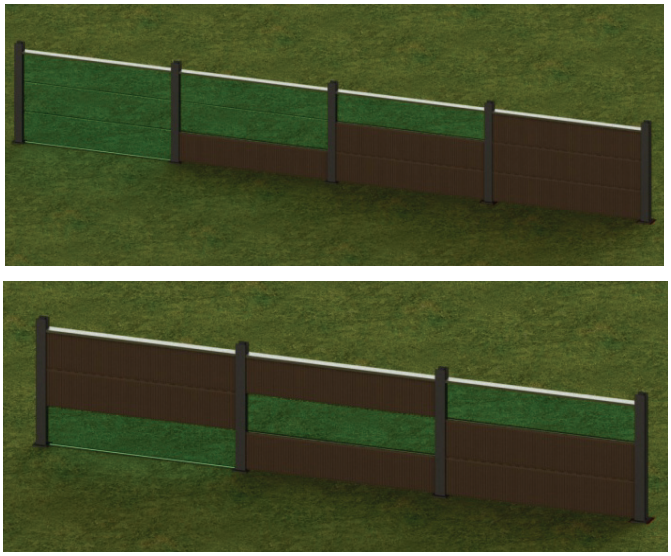


Figure 10 – *Combination of different types of panels for creation of a noise barrier*

4.6 Combination of the barrier with decorative elements

The character and appearance of an urban area should also be reflected in the noise barriers that are installed there as well as in the selection of materials for them. It is also the chance for architects and artists to leave something by which they could be recognized, so it is not often a case that one of the requirements is a special decorative module mounted on the barrier wall or artistic painting of barrier walls.



Fig. 11 – *Combination of the barrier with decorative elements*

4.7 Combination of barriers with planting

The rural environment is characterized by open space, natural trees and bushes. Artifical materials used for barriers will certainly be in contrast with this environment. Therefore, instead of barriers, natural obstacles in the form of earth mounds are usually made in rural areas, and when it is necessary to install barriers, they are usually combined with natural planting whose task is to conceal their visibility.



Fig. 12 – *Combination of barriers with planting* [2]

5. CONCLUSION

Development of *configurable products* based on a modular structure of products is nowadays used as one of the main manners to solve the problem of adapting products to individual requirements of users. Although the products formed in this way are predefined, for the purpose of satisfying a wider range of customers' requirements the market is offered a considerably larger number of product variants with a relatively small number of components (modules), and the period for appearing of a product on the market is considerably shorter.

The project TP37020 has been dealing, to a great extent, with development of configurable traffic noise barriers. The final result of the project should be new technical solutions which will be offered to domestic companies as a new production programme or as an addition to the existing production programme. It is a chance for employing domestic industrial capacities and significant money-saving because the price of a noise barrier in the European Community, depending on its characteristic, size, etc. is around 1,000,000€ per kilometer.

ACKNOWLEDGEMENT

The paper is a part of the research done within the project TR37020. The authors would like to thank to the Ministry of Education and Science of the Republic of Serbia for supporting this research.

REFERENCES

[1] M.Praščević, D.Cvetković: Environmental Noise, University of Niš, Fakultet zaštite na radu, Niš, 2005.

[2] B. Kotzen and C. English, *Environmental Noise Barriers, A guide to their acoustic and visual design*, Second edition, Taylor & Francis e-Library, London and New York, 2009.

[3] D. Marjanović: *Sustav za konfiguriranje proizvoda modularne arhitekture*, magistarski rad, Sveučilište u Zagrebu, Fakultet strojarstva i brodogradnje, Zagreb 2003.

[4] G.G. Fleming, H.S. Knauer, C.S.Y. Lee, S. Pedersen: *Noise Barrier Design Handbook, Highway Traffic Noise*, http://www.fhwa.dot.gov/environment/noise/noise_barriers/design_construction/design/index.cfm

[5] M. Kolarević, Z. Šoškić, Z. Petrović, B. Radičević:*Noise Protection In Urban Environment-Description Of A Project*, Mechanics, Transport, Communications, Academic journal,Todor Kableshkov University of Transport,Sofia, ISSN 1312-3823, issue 3/2011, pp.IV-69-IV-78.

[6] R. E. Klingner, M. T. McNerney, I. Busch-Vishniac: *Design Guide For Highway Noise Barriers*, Research Report 0-1471-4, Center for Transportation Research The University of Texas at Austin, November 2003

[7] H. Knauer, S. Pedersen: *FHWA Highway Construction Noise Handbook*, Highway Traffic Noise, http://www.fhwa.dot.gov/environment/noise/construction_noise/handbook/handbook00.cfm#ack

[8] R. F. Blum: *A Guide to Visual Quality in Noise Barrier Design*, Highway Traffic Noise, http://www.fhwa.dot.gov/environment/noise/noise_barriers/design_construction/visql/acknowledge.cfm

[9] *Guidelines on Design of Noise Barriers*, Environmental Protection Department and Highways Department Government of the Hong Kong SAR, Second Issue, January 2003

[10] *Cutting down noise with precast concrete and masonry barriers,* British Precast , 2005, http://www.britishprecast.org/documents/CuttingDownNoise.pdf

[11] B. Berglund, T. Lindvall, D. H. Schwela (editors). *Guideli-nes for community noise. WHO. World Health Organization 1999. www.who.int/docstore/peh/noise/guidelines2.html*

[12] A. Zlatković, *Analysis of railway vehicles noise management,* Master thesis, Faculty of Traffic Engineering, Belgrade, 2010.

[13] *Design Guide For Environmental Barrier,* Volume 10 Section 5, Part 1 HA 65/94, 2001

[14] *Environmental Barriers: Technical Requirements,* Volume 10 Section 5, Part 2 HA 66/95, *2001.*

[15] *Highway Traffic Noise Analysis And Abatement Policy And Guidance* by U.S. Department of Transportation, Federal Highway Administration, Office of Environment and Planning Noise and Air Quality Branch, Washington, D.C., June 1995

[16] *Directive 2002/49/EC* of The European Parliament and The Council of The European Union

[17] Serbian standard ISO 1996-1,2, Official Gazette of Republic of Serbia,

[18] Law on environmental noise protection of Republic of Serbia, Official Gazette of Republic of Serbia, No. 36/2009

[19] Regulation on noise indicators, limiting values and methods for estimation of noise indicators, annoyance and detrimental effects of noise, Official Gazette of Republic of Serbia, No. 75/2010

[20] National strategy of sustainable development, Government of Republic of Serbia, Belgrade 2008

[21] http://www.mfkv.rs/urbanoise

University of Nis
Faculty of Occupational Safety

„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

ANALYSIS OF MATERIALS USED FOR PRODUCTION OF NOISE PROTECTION BARRIERS

Mišo Bjelić, Miomir Vukićević, Aleksandra Petrović, Marina Pljakić

University of Kragujevac, Faculty of Mechanical and Civil Engineering, Kraljevo, bjelic.m@mfkv.kg.ac.rs

Abstract - *Wide range of materials is used in production of noise protection barriers. Selection of proper material affects many characteristics of barriers such as durability, acoustic properties, manufacturing and assembly costs, maintenance, aesthetics, etc. This article shows analysis of main advantages and disadvantages of the commonly used materials for noise protection barriers in order of its proper selection from the standpoint of design and production.*

1. INTRODUCTION

Development of technology and industrialization in the 20th century was accompanied by the rapid development of transport and transport infrastructure. Consequence of this development was increase in noise levels as well as prolongation of the period in which the noise level is higher than allowed.

In order to decrease level of noise, developed countries have started setting up noise protection barriers as the most reasonable solution since middle of 20th century. Design of the the barriers offers many choices to the designers, and this paper provides an analysis of the opportunities offered to the designers by the choice of materials used for construction of the barrirs.

2. DESIGN CONSIDERATIONS

Noise barriers must fulfil many requirements in order to provide effective noise reduction. The main group of requirements are related to the acoustic properties of barrier.

Acoustical design considerations include [1]:

- Barrier material,
- Barrier locations,
- Dimensions and shapes of the barriers.

A second group of design considerations includes non-acouctical aspects [1]:

- Engineering requirements,
- Safety,
- Environmental requirements,
- Maintenance,
- Material selection.

In both groups of considerations, acoustic and non-acoustic, barrier materials are very important factor. In the text that follows, an overview of the most commonly used materials for noise protection barriers is given, as well as analysis of the advantages and disadvantages of their use.

3. BARRIER MATERIALS

In general, there are two types of noise barriers:

- Reflective type,
- Absorptive type.

As well as barriers, materials can be categoized in the same way. Most commonly used materials for production of noise barriers are:

- Concrete,
- Wood,
- Metals (steel and aluminium),
- Transparent materials,
- Earth berms.

3.1 Concrete

Concrete is one of the most commonly used structural materials, and as such is used in the construction for noise protection. Concrete barriers can be prefabricated (which are relatively expensive) or can be cast in-situ.



Fig 1. *Concrete noise barrier*

Main advantages of concrete as material for noise protection barriers are [2]:

- Flexibility in design,
- Acoustically effective,
- Durable and weathers well,
- Long design life.

Main disadvantages of concrete as material for noise protection barriers are [2]:

- High density which leads to large weight,
- It is often used without appropriate design,
- It can be difficult to ensure quality control with concrete cast in-situ

Strenght of cement which is used must be at least 32.5 and mixture of aggregates must be in accordance with EN 13242, [3].

3.2 Wood

Wooden timber is often used for production of noise protection barriers. Not all types of wood can be used for barries. Only coniferous wood (spruce, fir, pine) that is dried in the air can be used. Wood must be treated with proper chemical preservatives.

Main advantages of wood as material for noise protection barriers are:

- Treated timber can last up to 50 years,
- Aesthetically is often preferred by people,
- Simple and often easily available designs,
- Relatively fast construction times.

Main disadvantages of wood as material for noise protection barriers are:

- Acoustic integrity and shortened design life is a problem due to the prevalent use of inappropriate timber and poor design and construction,
- Timber is not easily cleaned, requiring painting over every time it occurs,
- Soil can rot timber and it is preferable that timber does not come into contact with soil.



Fig 2. *Wooden noise barrier*

Quality of wooden timber must be in accordance with EN 1611-1, [3]:

- Wooden structural elements, class G4.3,
- Back wall – wooden panels – class G.4.2,
- Front wall – class G 4.1.

3.3 Metals

Most often used metals in production of noise barriers are:

- Mild Steel,
- Stainless steel,
- Aluminium.

Mild steel is the least expensive and most common of all metals used in construction. It should be corrosion protected by hot galvanizing. Layer of zinc must be at least 76μm thick, [3]. It can also be coated with plastisols, bonded powders, and enamel paints or it can be produced as self protecting weathering steel. Aluminium and stainless steels are commonly used for absorption or deflection elements.

Main advantages of metals [2]:

- Can be made relatively lightweight and easy to fix,
- Dual leaf sheet metal systems or panels can be used for absorptive barriers using a perforated metal front face and a solid unperforated metal rear face. The cavity can contain fibre glass or other noise absorbing materials,
- Modular panel systems are available with the same advantages as modular concrete or timber panels.

Main disadvantages [2]:

- Surface finishes may not be visually suited to all locations,
- Relatively heavy framing and fixing may be required for steel panels,
- High rate of expansion in hot weather,
- Lightweight panels are easily damaged.



Fig 3. *Metal noise barrier*

3.4 Transparent materials

Main characteristic of transparent materials is to allow light to areas which otherwise be placed in the shadow of barriers. Panel material which are used for barriers are made of either glass or a clear plastic product such as Plexiglas, Lexan, or Acrylic. Glass panels are commonly made of single tempered or laminated tempered glass sheets. Both plastics and glass can be tinted. Transparent materials are noise refleting and their use might be restricted where reverbration would cause problems.

Main advantages [2]:

- Allows for maintenance of views,
- Transparent panels can be used where a reduction in visual bulk is required,
- Improved public safety

Main disadvantages [2]:

- Expensive compared to alternatives,
- Glass easily broken, acrylic easily scratched;
- Glare from reflections of the sun or headlights,
- Plastics can be a fire hazard,
- High maintenance costs,
- Transparency can be affected by weather and temperature changes,
- Privacy of residential areas can be compromised.

3.5 Earth berms

Any type of earthy materials that provide stability can be used for earth berms. Quality of those materials must be in accordance with demands which are specified in specific technical conditions for groundwork.

Main advantages of earth berms [2]:

- Use of excess fill from road construction,
- Limited possibility for gaps developing, breakages or other acoustic integrity/maintenance issues,
- More aesthetically pleasing,

Main disadvantages [2]:

- Require a large amount of space,
- On certain ground, settlement may become an issue due to bund weight,
- May require more maintenance if grassed or inappropriately planted.



Fig 4. *Earth berms*

3.6 Other materials

All other materials that are necessary for production of noise barriers like, adhesives, paints, etc.

4. CONCLUSION

A wide range of different types of materials provides a rational choice of barrier materials with respect to acoustic and non-acoustic considerations as well as cost effectiveness.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to Serbian Ministry of Education and Science for support through project TR37020.

REFERENCES

[1] B. Cotzen and C. English, *Environmental Noise Barriers*, New York:Taylor & Francis, 2009.

[2] NZ Transport Agency, *State Highway Noise Barrier Design Guide*, Wellington:NZTA, 2010.

[3] "Smjernice za projektovanje, građenje, održavanje i nadzor na putevima - Knjiga 1: Projektovanje - Dio 1: Projektovanje puteva - Poglavlje 6: Put i životna sredina", Sarajevo/Banjaluka, 2005.



University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

ANALYSIS OF TRAFFIC NOISE PROBLEM IN STAGES OF ROAD DESIGN

Snežana Radulović Jevremović[1], *Vladimir Babić*[1]

[1] Highway Institute, Belgrade

Abstract - *Road design process involves a series of hierarchy ordered phases introduced by methodology of road planning and designing. Implementation of the methodological steps will provide us with sufficient certainty and reliability to make the necessary decisions. As the aspect of conservation and protection of environment is one of the important objectives in the design process, it is necessary to quantify the adverse impact on the environment and their methodological understanding through all phases.*

Roads as surfaces where traffic is being implemented and that connect populated areas, facilitating travel and economic exchange of goods, have become the dominant noise sources in the area through which they pass. Monitoring of traffic noise and noise source analysis showed that the dominant sources of noise is contact tire-pavement and the mechanical assembly of vehicles. The ratio of these quantities are changing with increasing speed, but separately for each source.

The paper will be closer view and will clarify the issue of noise from traffic and its quantification through all phases of project documentation. Adverse effect of traffic noise is observed and evaluated first during the Preliminary design of the project that determines the optimal corridor, then through the Conceptual project design by which the optimal route within the selected corridor will be selected. The final stage, the Main and Executive project designs, will determine the optimal engineering solutions that are implicit in the implementation of environmental protection measures.

The road design process involves a series of phases presented by methodology of planning and design. Conducting methodological steps helps us to make the necessary decisions with sufficient certainty and reliability. As aspect of conservation and environmental protection is one of the important objectives in the design process, it is necessary to quantify adverse impacts on the environment and their methodological understanding across all phases of the road design process.

Roads as areas where traffic is carried and that connect residential areas, allowing travel and economic exchange of goods, have become the dominant noise sources in the area through which they pass. Monitoring and analysis of noise sources shows that the dominant sources of traffic noise is the contact between the tire and pavement and mechanical assemblies of vehicles. The ratio of these values will change with increasing speed, but different for each dominant source, which further complicates the analysis of the problem.

The process of road design is a series of hierarchical decision-making procedures. Each of the design phases involves iterative testing of possible solutions and making decisions about the optimal solution (Figure 1). Environmental protection is methodologically involved in all phases of the planning and road design. Adverse effect of traffic noise being observed and evaluated during the first tier of project design, the General design that defines the optimal corridor, then through the Conceptual design on the basis of which defines the optimal route within the selected corridor. The final phase, Main and implementation project design is to determine optimal engineering solutions and provide technical documentation of performing details that are implicit in the implementation of environmental protection measures.

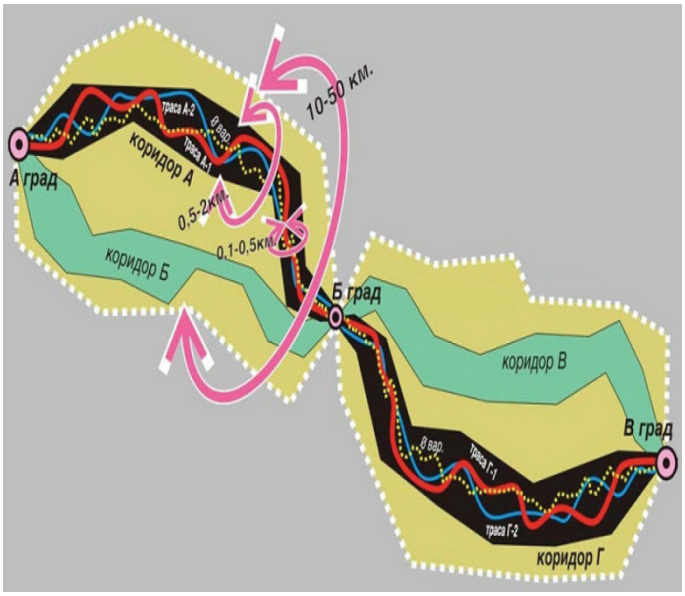


Fig1. *Example of variant solutions within General design*

The General project design represents the first step in the formation and collection of the necessary documents to verify the spatial and economic conditions of the road, when it comes to designers. Modern approach to road design involves satisfying the needs for mobility and safety, while respecting the need to preserve the environment, as well as the needs of the local community. This approach requires some flexibility in the design criteria and encourages creativity of design process that takes into account the specific requirements of the environment.

At the General desing noise is analyzed in order to evaluate alternative solutions in the selection of optimal route corridors. A team of designers will be acquainted with the limitations arising from environmental considerations by environmental specialists. Map of limits is a graphical interpretation showing the influence and vulnerability of environmental potentials in the area through which the road corridor passes. Map is also a superposition of all individual map limit. Map limits of traffic noise contains all recorded environmental potentials in the corridor zone and the zone of influence for all in relation to the input data.

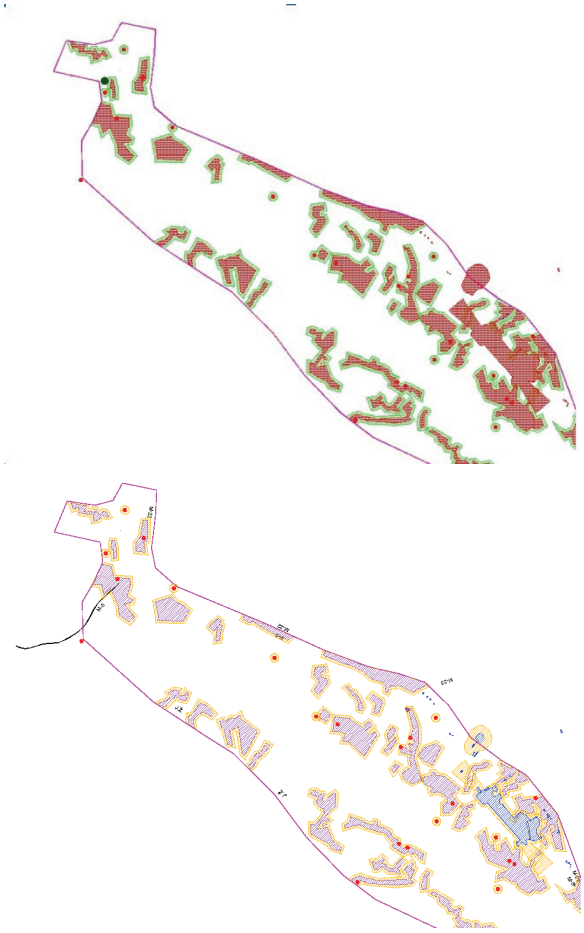


Fig2. *Maps of limits for corridor Pojate - Preljina*

Information about vulnerable environmental potentional are to be presented to the road designers refer to options that are available to the designer in the selection of geometric, situational and leveling elements in order to minimize negative effects. It is desirable to lead the central line of the road to the greatest distance of objects, particularly when it comes to housing, schools, kindergartens, hospitals and others noise sensitive areas. Designers can make a recommendation on which sites it is desirable to lower the central line of road to the field surface, ie. where it should be placed in cut. If the route is in the bank, then to try to provide enough space for the implementation of noise mitigation measures that are visually acceptable, less often a side effect of the mitigation and other negative influences. This refers to the vegetation with noise reduction effect that require the most space, planted in combination with protective embankment, noise protection berms that are favorable if there is excess soil, steep walls and so on. The earlier we detect potential emission limit values are exceeded, at our disposal is a larger selection of measures to reduce or eliminate these overruns.

With Conceptual design proces the optimal route within selected, optimal, corridor is defined. As with selection of optimal corridor under the General design, this level of design is also mainly about optimisation of build cost, maintenace costs and society benefits. One of many indicators that is analyzed is influence of noise from traffic on environmental potentials in area. Traffic and transtortation study which includes analizis of traffic by categories of vehicles and construction design of road are source of imput data necesery for noise calculation. Regarding the decisions made on General design level, during Conceptual design process it is possibile to present problem from trafic noise in relevant way. Based on the calculation of noise emission, propagation and immision we have data on influence that the road have on surrounding area.

On Conceptual level of road design it is possibile to define endangered objects, areas or spots, to do an analysis for observed area and to compare results with limit values for those environmental potentials. If there is a exceeding of those levels then it is neccesery to point out those locations and ways in which those levels can be mitigated. With a completion of General design, the variety of mitigation solutions is reduced and it mostly refers to engineering construction for noise protection. Those are primarily barriers to noise propagation in a form of noise protection walls or noise reduction berms. Beside that measures can also be:

1) intervention on the source of noise, which implies constructing SMA porous asfalt,
2) intervention on the noise imision spot, which implies intervention on building fasades as also improving sound isolation of windows.

On this level of design the construction for noise protection is defined with its place, footprint, acoustic characteristics and based on bill of quantities and costs the estimated cost of investment which is needed to lower the noise levels within maximum alowed leves. With these it is possibile to make a cost benefit analysis and help decision makers to deside will they protect environmental potential or not.

On the level of Main design the design of tehnical measures for environmental protection is compiled. It completly elaborates protection measures, as consequence of noise disturbance within area. Input data for noise calculation are more extensive and precise then on previous level of design, the 3d model of terrain is created based on design of completly modified terrain with road surfaces, slopes, berms, cuts, feels, bridges, supporting walls, all types of buildings, areas with acoustic properties etc.

In practice for a long time, until recently, in Serbia was in use recommendations for Germany federal road administration RLS. From 2010 as domestic standard is implemented French national standard which recommends use of NMPB-96 for traffic noise calculation. These new calculation metod and coresponding standards are more favorable to acoustic properties of surfaces over wich noise is emited then German, so there is significant difference in noise levels calculated useing these two standards.

The application of software packages can alow us to create a map of aquivalent noise levels of entire area of influence in short period of time, alowing us to visualy present results of noise calculation. The map itself do not present sufficient information of need to implement protection measures to the experts, but it can be used to present levels of exposure to a decision makers and to the public.

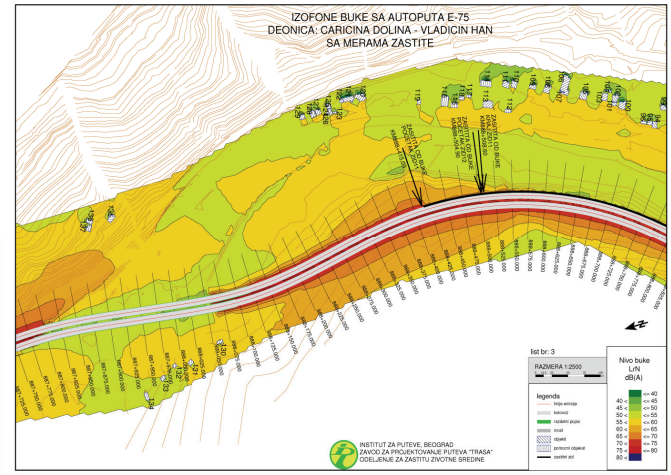


Figure 3 *Example of map of equvalent noise levels*

Computers allow us to design noise protection barriers, with their acoustical properties, to a sufficient accuracy. Construcion need to be defined in horizontal and vertical plane, after that there must be a test of stability of construction. When construcion pass all tests then the detail design of all conections and mutual fastening of individual elements is done. Also the bill of quantities and the bill of cost for of works and material needed for construction is formed. There are some more requirements that noise protection barriers must meet, like safety, ressistance to weather conditions, constant color and shape, use of waterproof material, impact ressistance, easy maintenance, ambient harmony in environment.



Figure 4 *Example of noise protection wall*

Main design also contains monitoring of environment. As for noise monitoring implies measuring of current levels of noise on specific objects along the section of road. Those values will be compared to the levels measured when road was completly build and when traffic gets it full extent. That way it is possibile to authenticate the efficiency of the measures and if neccesery to make some adjustments.

The process of planning and designning, alow us through its levels and medological construction possibilities to protect environment from the start of project. It is necessery that environmental demands be recognized from society and authorities in process of decision-making in order to assign a valid value to these criteriums. Making the right decisions in planning and designning process, when it comes to traffic noise, can make significant savings of costs and build time, and to ensure satisfactory quality of life on observed are.



University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

PERIODIC SOLUTIONS FOR THE NONLINEAR OSCILLATOR $\ddot{x}+(1+\dot{x}^2)x=0$

Nicolae Herişanu[1], *Vasile Marinca*[2]

[1] "Politehnica" University of Timişoara, Faculty of Mechanical Engineering, Romania, herisanu@mec.upt.ro
[2] "Politehnica" University of Timisoara, Faculty of Mechanical Engineering, vmarinca@mec.upt.ro

Abstract - *The Optimal Variational Iteration Method (OVIM) is introduced and applied to calculate periodic solutions of the nonlinear oscillation having quadratic dependence on the velocity. The main advantage of this procedure consists in that it provides a convenient way to control the convergence approximate periodic solutions in a very rigorous way. This approach does not depend upon any small or large parameters.*

1. INTRODUCTION

The perturbation method is one of the commonly used quantitative approach for analyzing nonlinear problems [1], [2]. The perturbation method is valid in principle only for problems containing small parameters. Its basic idea is to transform, by means of a small parameter, a nonlinear problem into an infinite number of linear problems, or a complicated linear problem into an infinite number of simpler ones. Therefore, the small parameters play a very important role in the perturbation method. It determines not only the accuracy of the perturbation approximations, but also the validity of the perturbation method itself. However, in science and engineering exists many nonlinear problems which do not contain any small parameters, especially those having strong nonlinearity. In consequence, it is necessary to develop and improve some nonlinear analytical techniques which are independent on small parameters.

There exists a wide body of literature dealing with the problem of approximate solutions to nonlinear equations with various different methodologies. Many different approaches have been proposed, such as the perturbation iteration method [3], some linearization methods [4], [5], the Adomian decomposition method [6], the modified Lindstedt-Poincare method [7]. The variational iteration method was proposed by J.H. He [8], [9] and has been proved by many authors to be a powerful mathematical tool for various kind of nonlinear problems.

Mickens et al. [10], [11], [12] had published two Lindstedt-Poincare methods and harmonic balance method for the nonlinear oscillator

$$\ddot{x}+(1+\dot{x}^2)x=0 \tag{1}$$

with initial conditions

$$x(0)=A,\quad \dot{x}(0)=0 \tag{2}$$

where the dot denotes the derivative with respect to time variable t. In Ref.[11], the author states that the oscillator has the interesting feature that its angular frequency is singular or not defined at finite values of A when standard perturbation procedures are used. He also demonstrated that the observed singularities occurring in the various methods to calculate approximate solutions for Eq.(10) are therefore artifacts of the perturbation methods and thus indicate limitations of these techniques.

They calculated the angular frequency by means of the first-order harmonic balance method and they obtained the following expression:

$$\omega(A)=\frac{2}{\sqrt{4-A^2}} \tag{3}$$

which is not defined for amplitudes of magnitude equal to or larger than two in value.

A new expression for the approximate frequency are obtained by Belendez et al. [13], [14] using a modified Lindstedt-Poincare perturbation method.

In this work, the OVIM is applied to construct accurate approximate analytic periodic solutions and frequencies of Eqs.(1) and (2). This method introduces a reliable and efficient process for a wide variety of scientific and engineering applications, linear or nonlinear, homogeneous or inhomogeneous equations and systems of equations as well.

In the case of our procedure, initial guess approximations contain more unknown parameters than the boundary conditions. Some of these parameters can be identified from initial/boundary conditions and the rest of then can be identified optimally, so that the residual is minimized.

The iterative process is constructed by a general Lagrange multiplier, which can be identified optimally via variational theory. This method is effective and accurate for nonlinear problems with approximations converging rapidly to accurate solutions after only one iteration.

2. THE OPTIMAL VARIATIONAL ITERATION METHOD

We consider the following nonlinear equation

$$\ddot{x}+\Omega^2 x+f(t,x,\dot{x},\ddot{x})=0 \tag{4}$$

with the initial conditions

$$x(0)=A,\quad \dot{x}(0)=0 \tag{5}$$

where f is assumed to be a nonlinear function, which may be expanded in a Fourier series and $\dot{x} = dx/dt$. We construct the iteration formula [8], [9], [15]

$$x_{n+1}(t) = x_n(t) + \int_0^t \lambda(\tau,t)[x_n''(\tau) + \Omega^2 x_n(\tau) + \\ + f(\tau,\tilde{x}_n,\tilde{x}_n',\tilde{x}_n'')]d\tau \tag{6}$$

where $\lambda(\tau,t)$ is the Lagrange multiplier and can be identified via variational theory and $\tilde{x}_n$ is a restricted variation: $\delta\tilde{x}_n = 0$. After calculating variation with respect to x_n, we obtain the following stationary conditions:

$$\lambda''(\tau,t) + \Omega^2\lambda(\tau,t) = 0, \\ \lambda(\tau,t)\big|_{\tau=t} = 0, \quad 1 - \lambda'(\tau,t)\big|_{\tau=t} = 0 \tag{7}$$

where prime denotes the derivative with respect to variable τ.

The Lagrange multipliers, therefore can be readily identified:

$$\lambda(\tau,t) = \frac{1}{\Omega}\sin\Omega(\tau - t) \tag{8}$$

and as a result, we obtain the following iteration formula

$$x_{n+1}(t) = x_n(t) + \frac{1}{\Omega}\int_0^t \sin\Omega(\tau - t)[x_n''(\tau) + \Omega^2 x_n(\tau) + \\ + f(\tau,x_n,x_n',x_n'')]d\tau \tag{9}$$

Eq.(6) is equivalent to

$$x_{n+1}(t) = x_0(t) + \frac{1}{\Omega}\int_0^t \sin\Omega(\tau - t) f(\tau,x_n,x_n',x_n'')d\tau \tag{10}$$

The initial conditions (5) for Eq.(2) are:

$$x_0(0) = A, \quad \dot{x}_0(0) = 0 \tag{11}$$

In our procedure, the initial solution $x_0(t)$ contains p>2 unknown parameters, which will be determined from the initial conditions given by Eq.(11) along with the stationary conditions of the residual functional (or other conditions obtained using other methods, such as Galerkin method, collocation method, least square method, and so on) and the condition of avoiding secular terms within the solution (10). Expanding $f(\tau,x_n,x_n',x_n'')$ in a Fourier series, we have:

$$f(\tau,x_n,x_n',x_n'') = \sum_{i=0}^{s} a_i^n \cos i\Omega\tau + \sum_{j=1}^{r} b_j^n \sin j\Omega t \tag{12}$$

and therefore, the approximation of (n+1)-th order (10) becomes

$$x_{n+1}(t) = x_0(t) + \frac{1}{\Omega}\Bigg[a_0^n + \frac{1}{2}a_1^n(t\sin\Omega t) + \frac{1}{2}b_1^n(t\cos\Omega t \\ + \frac{1}{2\Omega}\sin\Omega t) + \sum_{i=2}^{s}\frac{a_i^n(\cos\Omega t - \cos i\Omega t)}{(i^2-1)\Omega} + \\ + \sum_{j=2}^{r}\frac{b_j^n(j\sin\Omega t - \sin j\Omega t)}{(j^2-1)\Omega} \tag{13}$$

The solution (13) is so chosen that it contains no secular terms, which requires that the coefficients a_1^n and b_1^n in Eq.(13) disappear, i.e.:

$$a_1^n = 0, \quad b_1^n = 0 \tag{14}$$

For real systems, the expansion of the function $f(\tau,x_n,x_n',x_n'')$ usually contains only a small number of harmonics.

3. THE ANALYTICAL SOLUTION OF THE CONSIDERED OSCILLATOR

We rewrite Eq.(1) as

$$\ddot{x} + \Omega^2 x + (1-\Omega^2)x + x\dot{x}^2 = 0 \tag{15}$$

with the initial conditions

$$x(0) = A, \quad \dot{x}(0) = 0 \tag{16}$$

where Ω is the frequency of the system.

As an initial guess for $x_0(t)$ we choose:

$$x_0(t) = C_1\cos\Omega t + C_2\cos 3\Omega t + C_3\cos 5\Omega t \tag{17}$$

where C_1, C_2 and C_3 are unknown parameters. Taking into account Eqs.(17) and (16), one can be found that these parameters should obey the condition

$$C_1 + C_2 + C_3 = A \tag{18}$$

Within Eq.(15) we can identify the function f:

$$f(t,x,\dot{x}) = (1-\Omega^2)x + x\dot{x}^2 \tag{19}$$

From Eq.(10), for n=0 it is obtained

$$x_1(t) = x_0(t) + \frac{1}{\Omega}\int_0^t \sin\Omega(\tau - t) f(\tau,x_0,x_0')d\tau \tag{20}$$

where $f(\tau,x_0,x_0')$ is obtained by substituting Eq.(17) into Eq.(20) and we can write

$$f(\tau,x_0,x_0') = [(1-\Omega^2)C_1 + \Omega^2(\frac{1}{4}C_1^3 + \frac{9}{2}C_1C_2^2 + \\ \frac{25}{2}C_1C_3^2 + \frac{5}{4}C_1^2C_2 + \frac{17}{2}C_1C_2C_3 + \frac{21}{4}C_2^2C_3)]\cos\Omega t + \\ + A_1\cos 3\Omega t + A_2\cos 5\Omega t + A_3\cos 7\Omega t + A_4\cos 9\Omega t + \\ + A_5\cos 11\Omega t + A_6\cos 13\Omega t + A_7\cos 15\Omega t \tag{21}$$

where

$$A_1 = (1-\Omega^2)C_2 + \Omega^2(-\frac{1}{4}C_1^3 + \frac{9}{4}C_1^2C_3 + \\ + \frac{13}{2}C_1C_2C_3 + \frac{1}{2}C_1^2C_2 + \frac{9}{4}C_2^3 + \frac{25}{2}C_2C_3^2);$$

$$A_2 = (1-\Omega^2)C_1 + \Omega^2(-\frac{3}{4}C_1C_2^2 - \frac{7}{4}C_1^2C_2 + \\ + \frac{1}{2}C_1^2C_3 + \frac{9}{2}C_2^2C_3 + \frac{25}{4}C_3^3);$$

$$A_3 = \Omega^2(-\frac{15}{4}C_1C_2^2 - \frac{11}{4}C_1^2C_3 - \frac{7}{2}C_1C_2C_3 + \frac{5}{4}C_2C_3^2);$$

$$A_4 = \Omega^2(-\frac{15}{4}C_1C_3^2 - \frac{23}{2}C_1C_2C_3 - \frac{9}{4}C_2^3)$$

$$A_5 = \Omega^2(-\frac{35}{4}C_1C_2^2 - \frac{39}{4}C_2^2C_3);$$

$$A_6 = -\frac{55}{4}C_2C_3^2\Omega^2;$$

$$A_7 = -\frac{25}{4}C_3^2\Omega^2 \qquad (22)$$

Avoiding the presence of secular terms on the right-hand side of Eq.(21), we obtain the frequency Ω and another algebraic equation in C_1, C_2 and C_3:

$$\Omega^2 = \frac{4C_1}{4C_1 - C_1^3 - 18C_1C_2^2 - 50C_1C_3^2 - 5C_1^2C_2 - 34C_1C_2C_3 - 21C_2^2C_3} \qquad (23)$$

By substituting Eq.(17) into eq.(20) and (21) we obtain the approximate solution of the first order $x_1(t)$ as

$$x_1(t) = (C_1 - \frac{A_1}{8\Omega^2} - \frac{A_2}{24\Omega^2} - \frac{A_3}{48\Omega^2} - \frac{A_4}{80\Omega^2} - \frac{A_5}{120\Omega^2} - \frac{A_6}{168\Omega^2} - \frac{A_7}{224\Omega^2})\cos\Omega t + (C_2 + \frac{A_1}{8\Omega^2})\cos 3\Omega t + (C_3 + \frac{A_2}{24\Omega^2})\cos 5\Omega t + \frac{A_3}{48\Omega^2}\cos 7\Omega t + \frac{A_4}{80\Omega^2}\cos 9\Omega t + \frac{A_5}{120\Omega^2}\cos 11\Omega t + \frac{A_6}{168\Omega^2}\cos 13\Omega t + \frac{A_7}{224\Omega^2}\cos 15\Omega t \qquad (24)$$

where A_1, A_2,… are given by Eq.(22).

By substituting Eq.(24) into Eq.(1) it results the residual

$$R(t,\Omega,C_1,C_2,C_3) = \ddot{x}_1 + (1+\dot{x}_1^2)x_1 \qquad (25)$$

4. NUMERICAL EXAMPLES

To illustrate the accuracy of the OVIM, we compare previously obtained approximate solutions with the numerical integration results in two cases:

Case 4.1.: For A=0.8, following the procedure described above, we obtain:

$$C_1 = 0.826278; \quad C_2 = -0.0172694;$$
$$C_3 = -0.00900823; \quad \Omega = 1.06363$$

and therefore, the first-order approximate solution of Eq.(1) is

$$x_1(t) = 0.844957\cos\Omega t - 0.0370137\cos 3\Omega t - 0.00824147\cos 5\Omega t + 0.000323696\cos 7\Omega t - 0.0000214759\cos 9\Omega t \qquad (26)$$

Case 4.2.: For A=1, following the same procedure, we obtain

$$C_1 = 0.998479; \quad C_2 = -0.00139509;$$
$$C_3 = 0.00291606; \quad \Omega = 1.15367$$

and the approximate solution of the first-order in the form

$$x_1(t) = 1.02885\cos\Omega t - 0.031732\cos 3\Omega t + 0.00304778\cos 5\Omega t - 0.000166414\cos 7\Omega t \qquad (27)$$

Figures 1 and 2 show a comparison between the present solutions (26) and (27) respectively and the numerical solution of Eqs.(1) and (2).

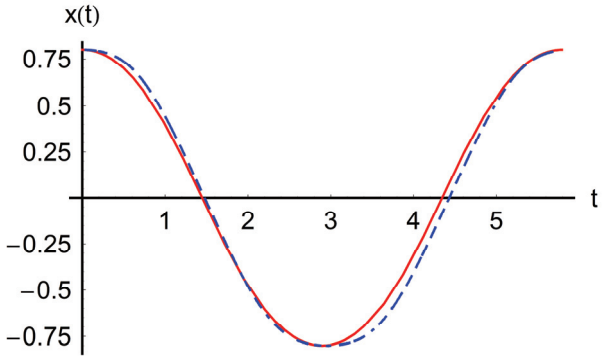


Fig.1. *Comparison between the present solution (26) and numerical solution for A=0.8*

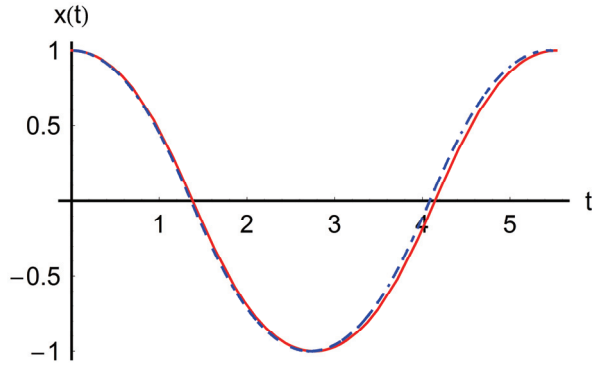


Fig.2. *Comparison between the present solution (27) and numerical solution for A=1*

Reading the above figures, one can be observed the accuracy of the obtained approximate analytical results, which are nearly identical with numerical ones.

5. CONCLUSIONS

In this paper we introduce the Optimal Variational Iteration Method (OVIM) to propose a new analytical approximate periodic solution to nonlinear equation $\ddot{x} + (1+\dot{x}^2)x = 0$. Our procedure is independent on the presence of small or large parameters in the considered equation. OVIM provides us with a simple and rigorous way to control and adjust the convergence of the solution through several convergence-control parameters C_i which are optimally determined. Our procedure is very rapid and effective in achieving approximate periodic solutions to the considered nonlinear oscillator. A very good agreement was found between the approximate analytical results obtained by this method and corresponding numerical solutions.

REFERENCES

[1] A.H. Nayfeh, D.T. Mook, Nonlinear Oscillations, John Wiley and Sons, N.Y., 1979

[2] A.H. Nayfeh, Introduction to perturbation techniques, John Wiley and Sons, N.Y., 1981

[3] J.H. He, Recent developments in asymptotic methods for nonlinear ordinary equations, Int. J. Comput. Numer. Anal. Appl., 2 (2002) 127-140

[4] A. Belendez, C. Pascual, C. Neipp, T. Belendez and A. Hernandez, An equivalent linearization method for conservative nonlinear oscillators, Int. J. Nonlin. Sci. Numer. Simul. 9 (2008) 9-17

[5] J.I. Ramos, Linearized Galerkin and artificial parameter techniques for the determination of periodic solutions of nonlinear oscillators, Appl. Math. Comput. 196 (2008) 483-493

[6] G. Adomian, A review of the decomposition method in applied mathematics, J. Math. Anal. Appl., 135 (1988) 501-544

[7] Y.K. Cheung, S.H. Chen, S.L. Lau, A modified Lindstedt-Poincare method for certain strongly non-linear oscillators, Int. J. Non-Linear Mech. 26 (1991) 367-378

[8] J.H. He, Variational iteration method: a kind of nonlinear analytical technique. Some examples, Int.J Non-Linear Mech., 34 (1999) 699-704

[9] J.H. He, Variational iteration method for autonomous ordinary differential systems, Appl. Math. Comput., 114 (2000) 115-123

[10] J. Beatty, R.E. Mickens, A qualitative study of the solutions to the differential equation $\ddot{x} + (1 + \dot{x}^2)x = 0$, J. Sound Vibr. 283 (2005) 475-477

[11] R.E. Mickens, Investigation of the properties of the period for the nonlinear oscillator $\ddot{x} + (1 + \dot{x}^2)x = 0$, J. Sound Vibr. 292 (2006) 1031-1035

[12] R.E. Mickens, Oscillations in Planar Dynamical Systems, World Scientific, Singapore, 1996

[13] A. Belendez, A. Hernandez, T. Blendez, C. Neipp, A. Marquez, Asymptotic representations of the period for the nonlinear oscillator, J. Sound Vibr. 299 (2007) 403-408

[14] A. Belendez, T. Belendez, A. Hernandez, S. Gallego, M. Ortuno, C. Neipp, Comments on « Investigation of the properties of the period of nonlinear oscillator $\ddot{x} + (1 + \dot{x}^2)x = 0$, J. Sound Vibr. 303 (2007) 925-930

[15] V. Marinca, N. Herişanu, Nonlinear Dynamical Systems in Engineering. Some Approximate Approaches, Springer Verlag, Berlin, Heidelberg, 2011

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

OPTIMAL VARIATIONAL METHOD FOR ANTISYMMETRIC, CONSTANT FORCE OSCILLATOR

Vasile Marinca[1], *Nicolae Herişanu*[2]

[1] "Politehnica" University of Timişoara, Faculty of Mechanical Engineering, Romania, vmarinca@mec.upt.ro
[2] "Politehnica" University of Timisoara, Faculty of Mechanical Engineering, herisanu@mec.upt.ro

Abstract - *The Optimal Variational Method (OVM) is proposed and applied to an antisymmetric constant force oscillator. The proposed approach involves the presence of some initially unknown convergence-control parameters which are optimally determined. Comparisons between the obtained results and exact ones or numerical results show that the OVM is very effective and convenient and provides highly accurate results.*

1. INTRODUCTION

It is known that computing Lagrangians to dynamical systems with more general Newtonian forces is nowadays applicable only to systems with force derivable from a potential function (basically, conservative systems). Strictly speaking, conservative systems do not exist in our Newtonian environment. As a result, the Lagrangian representation of conservative Newtonian system is, in general, only a crude approximation of physical reality. The problem of the existence of a Lagrangian or Hamiltonian can be studied with a variety of modern and sophisticated mathematical tools which include the use of functional analysis, prolongation theory and differential geometry, to mention only a few. This question is called "Inverse problem in Newtonian mechanics" [1]. And consists in the identification of the methods for the construction of a Lagrangian from given equations of motion.

In the last decades, considerable work has been invested in developing new methods for analytical and numerical solutions of nonlinear differential equations. There has been a great need for effective algorithms to avoid the onerous work required by traditional techniques, but it is difficult to obtain convergent results in the cases of strong nonlinearity.

Recently, many new approaches have been proposed for this purpose, such as various modified Lindstedt-Poincare methods [2], the Adomian decomposition method [3], the method of Lie group [4], the optimal homotopy asymptotic method [5], the optimal parametric iteration method [6,7] and so on.

A variational principle for nonlinear oscillations by constructing the Hamiltonian was studied in [8]. Variational principles have a great importance in physics and engineering since they establish connections between these disciplines and their applications are useful in devising various approximate techniques. Variational methods have been and continue to be popular tools for nonlinear analysis. They combine physical insights into the nature of the solution of the problem and the solutions obtained using possible trial functions are the best.

In this work we apply OVM to construct accurate approximations to periodic solutions and frequencies of nonlinear oscillators with discontinuities – antisymmetric constant force oscillators of the form

$$\ddot{u} + sign(u) = 0 \tag{1}$$

with initial conditions

$$u(0) = A, \quad \dot{u}(0) = 0 \tag{2}$$

where the dot denotes derivative with respect to the variable t.

In Eq.(1) there exists no small parameter, and therefore perturbation methods cannot be applied directly. This problem was studied among others for example by Liu [9] by means of the modified Lindstedt-Poincare method and by Wu et al. [10] which applied a method incorporating Newton's method and the harmonic balance method.

2. BASICS OF THE PROPOSED METHOD

In order to develop an application of the OVM, we consider the following differential equation of the nonlinear oscillator without forced terms:

$$\ddot{u} + f(u) = 0 \tag{3}$$

subject to initial conditions

$$u(0) = A, \quad \dot{u}(0) = 0 \tag{4}$$

where f is an arbitrary odd function of u. In our procedure, f does not need to contain a small parameter.

Introducing a new independent variable τ and a new unknown $x(\tau)$ as

$$\tau = \Omega t, \quad u(t) = Ax(\tau) \tag{5}$$

where Ω is the frequency of the oscillation of Eq.(3), then this becomes:

$$A\Omega^2 x'' + f(Ax) = 0 \tag{6}$$

where prime denotes the derivative with respect to the new variable τ.

The initial conditions (4) become

$$x(0)=1, \quad x'(0)=0 \tag{7}$$

If T is the period of the system, $T=2\pi/\Omega$, then the variational principle can be easily established if there exists a functional

$$J=\int_0^{\pi/2} L(\tau,x,x')d\tau \tag{8}$$

which admits as extremal the solutions of Eq.(6) and (7) where L is the Lagrangian of the system (6)

$$L(\tau,x,x')=-\frac{1}{2}A\Omega^2x'^2+F(x) \tag{9}$$

The function F is given by the equation

$$\frac{dF(x)}{dx}=f(Ax) \tag{10}$$

We assume that the approximate solutions of Eqs.(6) and (7) can be expressed as

$$\bar{x}(\tau)=\sum_{k=1}^{m} C_k \cos(2k-1)\tau \tag{11}$$

where C_k are arbitrary unknown constants at this moment and x is a positive integer number.

Substituting Eq.(11) into Eq.(8) it results in

$$J(C_1,C_2,...,C_m,\Omega)=\int_0^{\pi/2}\left[-\frac{1}{2}A\Omega^2\bar{x}'^2+F(\bar{x})\right]d\tau \tag{12}$$

Applying the Ritz method, we require

$$\frac{\partial J}{\partial C_1}=\frac{\partial J}{\partial C_2}=...=\frac{\partial J}{\partial C_m}=0 \tag{13}$$

From Eqs.(13) and from the initial conditions (7) which become

$$C_1+C_2+...+C_m=1 \tag{14}$$

we can obtain optimally the parameters C_i, i=1,2,…,m and the frequency Ω.

We remark that the expression (11) is not unique. We can alternatively choose another expression of the approximate periodic solution in the form

$$\bar{x}(\tau)=\sum_{k=1}^{n} C_k \cos(4k-1)\tau \tag{15}$$

and so on. With these constants C_i and the frequency Ω known, the approximate solution is well-determined.

3. ANTISYMMETRIC CONSTANT FORCE OSCILLATOR

The validity of the proposed approach is illustrated on the antisymmetric constant force oscillator (1). The Lagrangian of the dynamical system (1) or equivalent (6) is

$$L(\tau,x,x')=-\frac{1}{2}A\Omega^2x'^2+x\,sign(x) \tag{16}$$

If we note $g(x)=\text{sign}(x)$, where x is given by Eq.(11), then

$$g(x)=g(C_1\cos\tau)+g'(C_1\cos\tau)\sum_{k=2}^{m}C_k\cos(2k-1)\tau+ \\ +\frac{1}{2}g''(C_1\cos\tau)\left[\sum_{k=2}^{m}C_k(2k-1)\tau\right]^2+... \tag{17}$$

But $g'(C_1\cos\tau)=g''(C_1\cos\tau)=...=0$ and therefore, we obtain

$$sign(x)=sign(C_1\cos\tau)=sign(\cos\tau) \tag{18}$$

if we suppose that $C_1>0$. Using the identity [7]

$$sign(\cos\tau)=\frac{4}{\pi}(\cos\tau-\frac{1}{3}\cos3\tau+\frac{1}{5}\cos5\tau- \\ -\frac{1}{7}\cos7\tau+....) \tag{19}$$

and Eqs.(16) and (11), then the functional (12) can be written in the form:

$$J(C_1,C_2,...,C_m,\Omega)= \\ =-\frac{1}{8}\pi A\Omega^2\sum_{i=1}^{m}(2k-1)^2C_k^2+\sum_{k=1}^{m}\frac{(-1)^{k-1}}{2k-1}C_k \tag{20}$$

From the Eqs.(13) we obtain the constants C_k in the form:

$$C_k=\frac{4(-1)^{k-1}}{\pi A\Omega^2(2k-1)^3}, \quad k=1,2,...,m \tag{21}$$

Substituting Eqs.(21) into Eq.(14), we obtain the frequency

$$\Omega=2\sqrt{\frac{S_m}{\pi A}} \tag{22}$$

where

$$S_m=\sum_{k=1}^{m}\frac{(-1)^{k-1}}{(2k-1)^3} \tag{23}$$

Now, substituting Eqs.(21) and (11) into Eq.(5), we obtain the approximate solution of Eq.(1) as

$$\bar{u}(t)=\frac{A}{S_m}\sum_{k=1}^{m}\frac{(-1)^k}{(2k-1)^3}\cos(2k-1)\Omega t \tag{24}$$

where Ω and S_m are given by Eqs.(22) and (23) respectively.

In this way, the frequency and approximate periodic solution are well determined.

4. NUMERICAL EXAMPLES

In order to show the validity and accuracy of the OVM, we consider some distinct cases. For m=20 into Eq.(22) we obtain the approximate value of the frequency:

$$\Omega_{app}=\frac{1.110716273}{\sqrt{A}} \tag{25}$$

The exact value of the frequency is known:

$$\Omega_{ex}=\frac{1.110720735}{\sqrt{A}} \tag{26}$$

which means that a very good approximation is found for the frequency.

If we consider $m = 2$, then from Eq.(23) it results S_{20}=0.968938362 and therefore the approximate solution (24) becomes

$$\begin{aligned}\bar{u}(t) = A(&1.0320573\cos\Omega t - 0.03822434\cos 3\Omega t + \\ &+ 0.00825645914\cos 5\Omega t - 0.003008913\cos 7\Omega t + \\ &+ 0.0014157166\cos 9\Omega t - 0.0007754\cos 11\Omega t + \\ &+ 0.00046975\cos 13\Omega t - 0.00030579\cos 15\Omega t + \ldots\end{aligned} \tag{27}$$

where Ω is given by Eq.(25).

Case 4.1.: In the first case, for A=1, the approximate solution (27) becomes

$$\begin{aligned}\bar{u}(t) = &1.032057393\cos\Omega t - 0.038224347\cos 3\Omega t + \\ &+ 0.008256459\cos 5\Omega t - 0.0030089136\cos 7\Omega t + \\ &+ 0.0014157166\cos 9\Omega t - 0.0007754\cos 11\Omega t + \\ &+ 0.00046975\cos 13\Omega t - 0.000305794\cos 15\Omega t + \ldots\end{aligned} \tag{28}$$

where Ω=1.110716273.

Case 4.2.: In the last case. For A=10, the approximate solution (27) can be written as

$$\begin{aligned}\bar{u}(t) = &10.32057393\cos\Omega t - 0.38224347\cos 3\Omega t + \\ &+ 0.08256459144\cos 5\Omega t - 0.030089136\cos 7\Omega t + \\ &+ 0.014157166\cos 9\Omega t - 0.007754\cos 11\Omega t + \\ &+ 0.004697575\cos 13\Omega t - 0.00305794\cos 15\Omega t + \ldots\end{aligned} \tag{29}$$

where Ω=0.351239325.

Figures 1 and 2 show the comparison between the present solutions (28) and (29) respectively and the numerical integration results obtained using a fourth-order Runge-Kutta scheme.

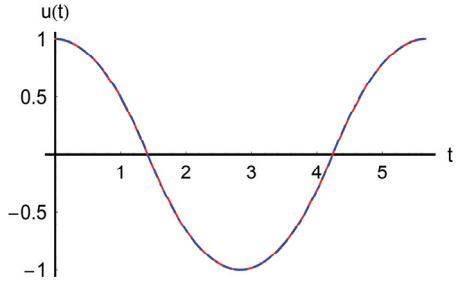


Fig.1 *Comparison between the numerical solution of Eq.(1) and approximate solution (28) for A=1, _____ numerical solution; _ _ _ _ _ _ _ approximate solutions*

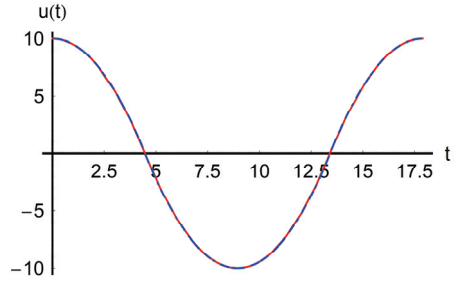


Fig.2 *Comparison between the numerical solution of Eq.(1) and approximate solution (29) for A=10, _____ numerical solution; _ _ _ _ _ _ _ approximate solutions*

It can be observed that the approximate results (28) and (29) are in excellent agreement with the numerical ones.

5. CONCLUSIONS

In the present paper, an optimal variational approach is employed to propose a new analytic approximate solution for a dynamical system with discontinuities. Our construction of the variational approach is different from the traditional approach especially concerning the involvement of some parameters C_i, called "convergence-control parameters", which ensure a fast convergence of the periodic solutions. Our procedure is valid even if the dynamical system does not contain any small or large parameters. The OVM provides us with a simple and rigorous way to control and adjust the convergence of the solutions. This new method is very rapid and effective and yields very accurate results comparing to those obtained via numerical integration using a fourth-order Runge-Kutta method. The method proposed in this paper can also be used to find analytic approximations to other conservative oscillators.

REFERENCES

[1] V. Obădeanu, V. Marinca, *The inverse problem in analytic mechanics*, Univ. Timişoara, 1992 (in Romanian)

[2] J.H. He, Modified Lindstedt-Poincare methods for some strongly nonlinear oscillators. Part.I. expansion of a constant, Int. *J. Nonlinear Mech.,* vol. 37, pp. 309-314, 2002

[3] G. Adomian, A review of the decomposition method in applied mathematics, *J. Math. Anal. Appl.*, vol. 135, pp. 501-544, 1988

[4] P.J. Olver, *Application of Lie group to differential equation*, Springer, N.Y., 1986

[5] V. Marinca, N. Herişanu, Application of optimal homotopy asymptotic method for solving nonlinear equations arising in heat transfer, *Int. Commun. Heat Mass Transf.*, vol. 35, pp. 710-715, 2008

[6] V. Marinca, Gh. Drăgănescu, Construction of approximate periodic solutions to a modified Van der Pol oscillator, *Nonlinear Anal. Real World Appl.*, vol. 11, pp. 4355-62, 2010

[7] V. Marinca, N. Herişanu, *Nonlinear dynamical systems in engineering. Some approximate approaches*. Springer Verlag, Berlin Heidelberg, 2011

[8] J.H. He, Preliminary report on the energy balance for nonlinear oscillations, *Mech. Res. Commun.,* vol. 29, pp. 107-111, 2003

[9] H.M. Liu, Approximate period of nonlinear oscillators with discontinuities by modified Lindstedt-Poincare method, *Chaos, Solitons and Fractals*, vol. 22, pp. 577-579, 2005

[10] B.S. Wu, W.P. Sun, C.W. Lim, An analytical approximate technique for a class of strongly nonlinear oscillators, *Int. J.Nonlinear Mech.,* 41 (2006) 766-774



University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

OPTIMAL HOMOTOPY PERTURBATION METHOD FOR NONLINEAR OSCILLATORS WITH A FRACTIONAL-ORDER RESTORING FORCE

Vasile Marinca[1,2], Remus-Daniel Ene[3]

[1] ”Politehnica” University of Timisoara, Faculty of Mechanical Engineering, Romania, vmarinca@mec.upt.ro
[2] Romania Academy – Timisoara Branch, CCTFA, Romania, vmarinca@mec.upt.ro
[3] ”Politehnica” University of Timisoara, Department of Mathematics, Romania, eneremus@gmail.com

Abstract - *Optimal Homotopy Perturbation Method (OHPM) is introduced and applied for solving nonlinear oscillators with a fractional-order restoring force. OHPM is highly efficient and it controls the convergence of the approximation series by means of unknown constants. A very good agreement was found between approximate and numerical solution, which proves that OHPM is very efficient and accurate.*

1. INTRODUCTION

Apart from a few exception, most engineering problems are nonlinear cannot be solved analytically by using the traditional methods. There are some approaches to obtain solutions of a nonlinear system. The most common and most widely studied method for nonlinear differential equations are the perturbation methods [1], [2] but almost all perturbation methods are based on such an assumption that a small parameter must exist in an equation. The approximate solutions obtained by perturbation methods are valid, in most cases only for small values of parameters. However, there is no criterion on how small parameters should be.

In recent years, a growing interest towards the application of the homotopy technique in nonlinear problems has appeared. The homotopy perturbation method (HPM) was first proposed by J. H. He [3] and has been shown to solve a large class of nonlinear problems effectively, easily and accurately with approximations converging to accurate solution. Later, in 2008 [4] Marinca and Herisanu presented a new homotopy approach, namely the optimal homotopy asymptotic method (OHAM) which proved to be another reliable approach to nonlinear problems, selecting the optimal values of some convergence-control parameters. In 2010 the homotopy perturbation method is extended by means of a set of the auxiliary functions, controlling the convergence of the solutions [5]. This is namely optimal homotopy perturbation method [6].

2. BASIC IDEAS OF OHPM

Firstly, we explain the ideas of the homotopy perturbation method, considering the nonlinear differential equation

$$L(u(\tau)) + N(u(\tau)) = 0, \tau \in \Omega \tag{1}$$

that is subject to the boundary condition

$$B\left(u, \frac{\partial u}{\partial \tau}\right) = 0, \tau \in \Gamma \tag{2}$$

where L is a linear operator, N a nonlinear operator, Γ is the boundary of the domain Ω and B a boundary operator. We construct the homotopy

$$H(u,p) = L(u) + pN(u) = 0 \tag{3}$$

for Eq. (1) where p is the homotopy parameter, $p \in [0,1]$.

From Eq. (3) it is obtain that

$$\begin{aligned} H(u,0) &= L(u_0) = 0 \\ H(u,1) &= L(u) + N(u) = 0. \end{aligned} \tag{4}$$

We remark that the changing of p from zero to unity corresponds to the changing of $H(u,p)$ from the initial guess $u_0(\tau)$ to $u(\tau)$. Topologically, this is a deformation and $L(u_0)$ and $L(u)+N(u)$ are therefore homotopic. If we assume that the solutions of Eq. (1) and (2) can be expressed in the form

$$u(\tau) = u_0(\tau) + pu_1(\tau) + p^2 u_2(\tau) + \ldots \tag{5}$$

then the approximate solutions of Eq.(1) and (2) can be readly obtained by taking

$$\tilde{u}(\tau) = \lim_{p \to 1} u(\tau) = u_0(\tau) + u_1(\tau) + u_2(\tau) + \ldots \tag{6}$$

which is the essence of the homotopy perturbation method.

We now introduce the basics of the new approach, the optimal homotopy perturbation method. In general the nonlinear operator $N(u)$ depends on τ, u, u' and u'', where primes denotes derivatives with respect to τ, so that

$$N(u) = F(\tau, u, u', u'') \tag{7}$$

Substituting Eq. (5) into Eq. (7) and expanding F in series with respect to the parameter p, we have

$$F(\tau,u,u',u'') = F(\tau,u_0,u_0',u_0'') +$$

$$+ p\left[u_1 F_u + u_1' F_{u'} + u_1'' F_{u''}\right](\tau,u_0,u_0',u_0'') +$$

$$+ p^2\left[u_2 F_u + u_2' F_{u'} + u_2'' F_{u''} + \frac{1}{2}u_1^2 F_{uu} + \right.$$

$$+\frac{1}{2}u_1'^2 F_{u'u'}+\frac{1}{2}u_1''^2 F_{u''u''}+u_1u_1'F_{uu'}+$$
$$+u_1u_1''F_{uu''}+u_1'u_1''F_{u'u''}](\tau,u_0,u_0',u_0'')+\ldots \quad (8)$$

where $F_u=\dfrac{\partial F}{\partial u}$. By introducing a number of unknown auxiliary functions $K_{ij}(\tau,C_i)$, $i, j=0,1,2,\ldots$ that depend on the variable τ and some constants C_1, C_2, ..., a new homotopy

$$\begin{aligned}H(u,p)&=L(u)+p[K_0(\tau,C_i)F(\tau,u_0,u_0',u_0'')]+\\&+p^2[K_{10}(\tau,C_j)u_1F_u(\tau,u_0,u_0',u_0'')+\\&+K_{11}(\tau,C_k)u_1'F_{u'}(\tau,u_0,u_0',u_0'')+\\&+K_{12}(\tau,C_l)u_1''F_{u''}(\tau,u_0,u_0',u_0'')]+\ldots=0\end{aligned} \quad (9)$$

can be written for Eq. (3) and a whole set of n-th order problems is obtained by equating the coefficients of like powers of p. More precisely, we have the following:

the zeroth-order problem

$$L(u_0)=0,\ B\left(u_0,\frac{\partial u_0}{\partial\tau}\right)=0,\ \tau\in\Gamma \quad (10)$$

the first-order problem

$$\begin{aligned}&L(u_1)+K_0(\tau,C_i)F(\tau,u_0,u_0',u_0'')=0\\&B\left(u_1,\frac{\partial u_1}{\partial\tau}\right)=0,\quad \tau\in\Gamma\end{aligned} \quad (11)$$

the second-order problem

$$\begin{aligned}&L(u_2)+K_{10}(\tau,C_j)u_1F_u(\tau,u_0,u_0',u_0'')+\\&+K_{11}(\tau,C_k)u_1'F_{u'}(\tau,u_0,u_0',u_0'')+\\&+K_{12}(\tau,C_l)u_1''F_{u''}(\tau,u_0,u_0',u_0'')+\ldots=0\\&B\left(u_2,\frac{\partial u_2}{\partial\tau}\right)=0,\quad \tau\in\Gamma\end{aligned} \quad (12)$$

and so on.

The function $K_0, K_{10}, K_{11}, K_{12},\ldots$ are not unique and be chosen such that the products $K_{ij}u_k'F_u$ and $u_k'F_u$ are of the same form. In this way, a maximum if only two iterations are required to achieve accurate solutions.

The parameters C_i that appears in the functions $K_{ij}(\tau,C_k)$ can be determined optimally, i. e. by considering the residual functional

$$J(C_i)=\int_a^b R^2(\tau,C_i)d\tau \quad (13)$$

and minimizing

$$\frac{\partial J}{\partial C_i}=0,\quad i=1,2,\ldots \quad (14)$$

for a and b in the domain of interest, and residual R is given by

$$R(\tau,C_i)=L(\bar{u})+N(\bar{u}) \quad (15)$$

where $\bar{u}$ is the approximate solution of order m:

$$\bar{u}(\tau)=u_0(\tau)+u_1(\tau)+\ldots+u_m(\tau) \quad (16)$$

Alternatively, the parameter C_i can also be determined by the least squares method, the Galerkin method and collocation method [6], etc.

The solution of Eq. (1) subject to the initial conditions (2) can immediately be determined by using OHPM once the parameters C_i (or convergence-control constants) are known. In short, the ideas of the proposed procedure is to construct a new homotopy (9) and the functions $K_{ij}(\tau,C_k)$ with constants C_k that can be determined optimally so that the convergence of the approximate solutions can be easily controlled.

3. NONLINEAR OSCILLATORS WITH A FRACTIONAL ORDER RESTORING FORCE

The following nonlinear oscillator, which has been studied by different authors [7-10]

$$\frac{d^2x}{dt^2}+ax^{\frac{1}{3}}=0 \quad (17)$$

with initial conditions

$$x(0)=A,\quad \frac{dx(0)}{dt}=0 \quad (18)$$

was introduced as a model "truly nonlinear oscillator" by Mickens [7], [8]. Eq. (17) is a conservative nonlinear oscillator with fractional power restoring force. We denote the angular frequency of these oscillations by Ω, and making the transformations

$$\tau=\Omega t,\quad x(t)=Au(\tau) \quad (19)$$

then Eqs. (17) and (18) become, respectively

$$\frac{d^2u}{d\tau^2}+u+\alpha u^{\frac{1}{3}}-u=0 \quad (20)$$

$$u(0)=1,\quad \frac{du(0)}{d\tau}=0 \quad (21)$$

where $\alpha=a\Omega^{-2}A^{-\frac{2}{3}}$. For Eqs.(20) and (19) we can establish the following homotopy

$$H(u,p)=u''+u+p\left[K_0(\tau,C_i)\left(\alpha u^{\frac{1}{3}}-u\right)\right]=0 \quad (22)$$

where prime denotes the derivation with respect to new variable τ.

The zeroth-order problem given by Eq. (10) becomes

$$u_0''+u_0=0,\ u_0(0)=1,\ u_0'(0)=0 \quad (23)$$

We obtain the solution:

$$u_0(\tau)=\cos\tau \tag{24}$$

Substitution of Eq. (24) into Eq. (11) gives

$$\begin{aligned} &u_1''+u_1+K_0(\tau,C_i)\left(\alpha\cos^{\frac{1}{3}}\tau-\cos\tau\right)=0\\ &u_1(0)=0,\quad u_1'(0)=0 \end{aligned} \tag{25}$$

Using the series expansion [9]

$$\begin{aligned} \cos^{\frac{1}{3}}\tau=\beta\Big(&\cos\tau-\frac{1}{5}\cos 3\tau+\frac{1}{10}\cos 5\tau-\\ &-\frac{7}{110}\cos 7\tau+\frac{1}{22}\cos 9\tau-\frac{13}{374}\cos 11\tau+\ldots\Big) \end{aligned} \tag{26}$$

where $\beta=1{,}1595952666393$, and substituting Eq. (26) into (25), we obtain

$$\begin{aligned} &u_1''+u_1+K_0(\tau,C_i)\Big[(\alpha\beta-1)\cos\tau-\\ &-\frac{\alpha\beta}{5}\cos 3\tau+\frac{\alpha\beta}{10}\cos 5\tau-\frac{7\alpha\beta}{110}\cos 7\tau+\\ &+\frac{\alpha\beta}{22}\cos 9\tau-\frac{13\alpha\beta}{374}\cos 11\tau+\ldots=0 \end{aligned} \tag{27}$$

We choose the auxiliary function K_0 as

$$K_0(\tau,C_i)=C_1+2C_2\cos 2\tau+2C_3\cos 4\tau \tag{28}$$

Substituting Eq. (28) into Eq. (27) gives

$$\begin{aligned} &u_1''+u_1+\left[\alpha\beta\left(C_1+\frac{4}{5}C_2-\frac{1}{10}C_3\right)-C_1-C_2\right]\cdot\\ &\cos\tau+\left[\alpha\beta\left(-\frac{1}{5}C_1+\frac{11}{10}C_2+\frac{54}{55}C_3\right)-C_2-C_3\right]\cdot\\ &\cos 3\tau+\left[\alpha\beta\left(\frac{1}{10}C_1-\frac{12}{55}C_2+C_3\right)-C_3\right]\cos 5\tau-\\ &-\alpha\beta\left(\frac{1}{55}C_1-\frac{1}{10}C_2+\frac{439}{374}C_3\right)\cos 7\tau+\alpha\beta\cdot \end{aligned} \tag{29}$$

$$\begin{aligned} &\left(-\frac{9}{170}C_2+\frac{1}{10}C_3\right)\cos 9\tau-\alpha\beta\left(\frac{13}{374}C_1+\frac{1}{55}C_3\right)\cdot\\ &\cos 11\tau-\frac{13}{374}\alpha\beta C_2\cos 13\tau-\frac{13}{374}\alpha\beta C_3\cos 15\tau=0 \end{aligned}$$

No secular terms in $u_1(\tau)$ requires eliminating contributions proportional to $\cos\tau$ in Eq. (29), such that we can write the frequency Ω in the form

$$\Omega=\frac{\alpha\beta(10C_1+8C_2-C_3)}{10A^{\frac{2}{3}}(C_1+C_2)} \tag{30}$$

From Eq. (29) we obtain an approximate solution u_1 in the form

$$\begin{aligned} u_1(\tau)=&\left[\alpha\beta\left(-\frac{1}{40}C_1+\frac{11}{80}C_2+\frac{27}{220}C_3\right)-\right.\\ &\left.-\frac{1}{8}C_2-\frac{1}{8}C_3\right](\cos 3\tau-\cos\tau)+\\ &+\left[\alpha\beta\left(\frac{1}{240}C_1-\frac{1}{110}C_2+\frac{1}{24}C_3\right)-\frac{1}{24}C_3\right]\cdot\\ &(\cos 5\tau-\cos\tau)-\alpha\beta\left(\frac{1}{2640}C_1-\frac{1}{480}C_2+\right.\\ &\left.+\frac{439}{17952}C_3\right)(\cos 7\tau-\cos\tau)+\alpha\beta\left(-\frac{9}{13600}C_2+\right.\\ &\left.+\frac{1}{800}C_3\right)(\cos 9\tau-\cos\tau)-\alpha\beta\left(\frac{13}{44880}C_1+\right.\\ &\left.+\frac{1}{6600}C_3\right)(\cos 11\tau-\cos\tau)-\frac{13\alpha\beta C_2}{62832}(\cos 13\tau-\\ &-\cos\tau)-\frac{13\alpha\beta C_3}{83776}(\cos 15\tau-\cos\tau) \end{aligned} \tag{31}$$

Substituting Eqs. (24) and (31) into (16) we obtain the first-order approximate solution of Eqs. (20) and (21) in the form

$$\bar{u}(\tau)=u_0(\tau)+u_1(\tau) \tag{32}$$

The first-order approximate solution of Eqs. (17) and (18) is obtained from Eqs. (32) and (19) and thus

$$\begin{aligned} \bar{x}(t)=&A\left[1+\frac{1}{8}C_2+\frac{1}{6}C_3+\alpha\beta\left(\frac{193}{8976}C_1-\right.\right.\\ &\left.\left.-\frac{27287}{209440}C_2-\frac{65899}{817600}C_3\right)\right]\cos\Omega t+\frac{A}{880}\cdot\\ &[\alpha\beta(-22C_1+121C_2+108C_3)-110(C_2+C_3)]\cdot\\ &\cos 3\Omega t+\frac{A}{2640}[\alpha\beta(11C_1-24C_2+110C_3)-\\ &-110C_3]\cos 5\Omega t+\alpha\beta A\left(-\frac{1}{2640}C_1+\frac{1}{480}C_2-\right.\\ &\left.-\frac{439}{17952}C_3\right)\cos 7\Omega t+\alpha\beta A\left(\frac{1}{800}C_3-\frac{9}{13600}C_2\right)\cdot\\ &\cos 9\Omega t-\alpha\beta A\left(\frac{13}{44880}C_1+\frac{1}{6600}C_3\right)\cos 11\Omega t-\\ &\frac{13}{62832}\alpha\beta AC_2\cos 13\Omega t-\frac{13}{83776}\alpha\beta AC_3\cos 15\Omega t \end{aligned} \tag{33}$$

4. NUMERICAL EXAMPLES

We illustrate the accuracy of the OHPM by comparing the approximate solutions previously obtained with the numerical results obtained using Wolfram Mathematica 6.0 software.

The first order approximate solution given by Eq. (33) is obtained in the case $a=1$, $A=1$ for the following values of the convergence-control constants C_i:

$$C_1 = 0{,}77887420, \quad C_2 = -0{,}095630393,$$
$$C_3 = 0{,}019327786, \quad \Omega = 1{,}080808926$$

$$\begin{aligned}\bar{x}(t) &= 1{,}017227439\cos\Omega t - 0{,}02052404\cos 3\Omega t + \\ &+ 0{,}004075603\cos 5\Omega t - 0{,}001202573\cos 7\Omega t + \\ &+ 0{,}000099212\cos 9\Omega t - 0{,}000228368\cos 11\Omega t - \\ &- 2{,}037693075\cdot 10^{-8}\cos 13\Omega t\end{aligned} \tag{34}$$

In the case $a = 1$, $A = 5$ the constants become

$$C_1 = 0{,}844134890, \quad C_2 = -0{,}028434457,$$
$$C_3 = 0{,}188258283, \quad \Omega = 0{,}633385584$$

and the first order approximate solution is given by

$$\begin{aligned}\bar{x}(t) &= 5{,}093317807\cos\Omega t - 0{,}109323855\cos 3\Omega t + \\ &+ 0{,}018212252\cos 5\Omega t - 0{,}004925524\cos 7\Omega t + \\ &+ 0{,}001256124\cos 9\Omega t - 0{,}001349528\cos 11\Omega t - \\ &- 1{,}284562626\cdot 10^{-6}\cos 13\Omega t\end{aligned} \tag{35}$$

Figures 1 and 2 present a comparison between the present solutions (34) and (35) respectively and the numerical solution of the Eqs. (17) and (18).

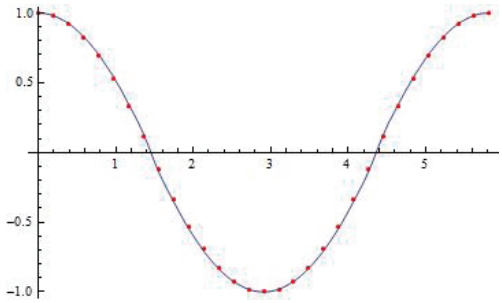


Fig.1 *Comparison between the present solution (34) and numerical solution for a=A=1: ___ numerical solution; …… approximate solution*

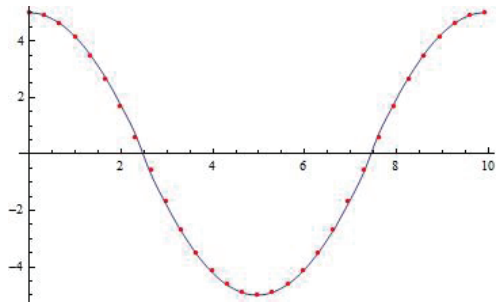


Fig.2 *Comparison between the present solution (35) and numerical solution for a=1, A=5: ___ numerical solution; …… approximate solution*

It is easier to emphasize the accuracy of the obtained results if we graphically compare the analytical solutions obtained through OHPM with the numerical ones.

5. CONCLUSIONS

In this paper we introduce a new optimal homotopy approach, namely the optimal homotopy perturbation method to propose a new analytic approximate solution to nonlinear oscillators with a fractional order restoring force. Our procedure is valid even if the nonlinear equation does not contain small or large parameters.

The proposed construction of homotopy is different from other approaches, especially referring to the auxiliary functions K_{ij} and the presence of some parameters $C_1, C_2, \ldots$ which ensure a rapid convergence of the solution. The OHPM provides us with a simple and rigorous way to control and adjust the convergence of the solution through a number of parameters C_i which are optimally determined. The main strength of the OHPM is its fast convergence since after only one iteration, the solution converges to the exact one, which proves that this procedure is very efficient in practice.

REFERENCES

[1] A.N. Nayfeh and D.T. Mook, *Nonlinear oscillations*, New York: John Willey and Sons, 1979.

[2] P. Hagedorn, *Nonlinear oscillations*, Oxford: Claredon Press, 1981.

[3] J.H. He, "A coupling method of homotopy technique and perturbation technique for nonlinear problems", *Int. J. Non-Linear Mech.*, vol. 35, pp. 37-43, 2000.

[4] V. Marinca, N. Herisanu, "Application of optimal homotopy asymptotic method for solving nonlinear equations arising in heat transfer", *Int. Commun. Heat Mass Transfer*, vol. 35, pp. 710-715, 2008.

[5] V. Marinca, N. Herisanu, "Optimal homotopy perturbation method for nonlinear differential equations", *Nonlin.Sci.Lett.A*, vol.1, pp. 273-280, 2010

[6] V. Marinca, N. Herisanu, *Nonlinear Dynamical Systems in Engineering - Some Approximate Approaches*, Springer, 2011.

[7] R.E. Mickens, "Analysis of nonlinear oscillations having nonpolynomial elastic terms", *Journal of Sound and Vibration*, vol. 255, pp. 789-792, 2002.

[8] R.E. Mickens, "A generalized iteration procedure for calculating approximations to periodic solutions of "truly nonlinear oscillators"", *Journal of Sound and Vibration*, vol. 287, pp. 1045-1051, 2005.

[9] R.E. Mickens, "Iteration method solutions for conservative and limit-cycles $x^{1/3}$ force oscillators", *Journal of Sound and Vibration*, vol. 292, pp. 964-968, 2006.

[10] A. Belendez, C. Pascual, S. Gallego, M. Ortuno, C. Neipp, "Applications of a modified He's homotopy perturbation method to obtained higher-order approximations of an $x^{1/3}$ force nonlinear oscillators", *Physics Letters A*, vol. 371, pp. 421-426, 2007.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

THE EXTREME DYNAMIC STATE OF MAIN MEMBERS OF FRAME SUPPORTING STRUCTURE

Goran Radoičić [1], *Miomir Jovanović* [1]

[1] *University of Niš, Faculty of Mechanical Engineering, A. Medvedeva 14, Niš, Serbia, goran.radoicic@jkpmediana.rs*

Abstract - *Tall frame structures, such as cranes, stackers and excavators, are characterized of large amplitudes (vibrations) caused by combination of different working effects. Numerical analyses of supporting structures can be successfully performed by applying modern software for dynamic analysis of machines in absence of experimental vibration analysis. This paper shows an application procedure of the finite element method to determine vibrations caused by shock regime. This type of analysis falls in the transient dynamics which corresponds to transient kinematic states of structural members. The paper presents a developed mechanical model and procedure for determination of the local dynamic effect on the responsible members of steel structure of selected tower crane. Kinematics of rapid lowering of load is first observed in simulation in a regular regime. It caused vibrations of the crane supporting structure with significant translations. Afterwards, an incident event with shock of load on ground due to rapid lowering is observed. Numerical analysis of the structure has shown the procedure to determine the most important data for researchers and designers (maximal and minimal stresses, maximal forces, vibrations). The investigations are supported by results of current measurements. Dynamical stability of the structure was numerical tested in a transient regime under the influence of larger load than the nominal. In that way, the real reserve of stability of tall object exposed to dynamics was researched.*

Keywords: *Finite element method, transient analysis, frame structure, vibrations, dynamic coefficient.*

1. INTRODUCTION TO VIBRATIONS OF STRUCTURE

Dynamic load of structures often has a shock character in practice. Special form of the shock effect is impulse. The impulse function is characterized by high intensity force in a short period of time. The impulsive dynamic load can particularly endanger the stability of tall frame structure such as tower cranes. In these structures, significant vibrations occur even at extreme working actions (e.g. fast lowering of load and sudden braking).

Tower crane **Potain 744e** is presented by a dynamic FEM (finite element method) model with finite number (n) degrees of freedom (DOF). The crane structure is composed of linear finite elements BEAM and ROD type, interconnected by effects of axial forces. The external forces (loads) act in connection nodes of rods, i.e. in finite elements of the frame structure. Attacking lines of these forces pass through contact nodes of the boom and trolley in the vertical direction. Translations of nodes which occur in the structure due to vibrations, have a spatial character (they are performed in global axes directions). Dominant strain direction is the vertical direction due to nature of perturbation force.

Equation of motion of structure with nDOF, under the influence of the external perturbation force $\{F(t)\}$, can be presented by general matrix form (1):

$$[m]\cdot\{\ddot{q}\}+[b]\cdot\{\dot{q}\}+[k]\cdot\{q\}=\{F(t)\} \qquad (1)$$

Which contains: inertial mass matrix $[m]$, viscous damping matrix $[b]$, stiffness matrix $[k]$, generalized coordinates q_i (i=1,...,n) and their the first and the second time derivate.

Solution of the system equations (1) is displacement vector $\{q(t)\}$ which represents the basic response of the structure on external dynamic excitation. By differentiating displacements in time the dynamical responses such as velocities and accelerations will be also obtained.

FEM, as a numerical method for approximate solving of differential equations of systems with finite number of DOF, has wide use in the transient response analysis of supporting structures. Appropriate softwares for these analyses require including several significant sizes in calculation [1], [2]. These are: overall structural damping G, element structural damping G_E, dominant circular frequencies ω* and ω**. The sizes of structural damping introduce the complex nature of damping in computation through the stiffness matrix $[k]$ which contains $[k_G]$ – global stiffness matrix and $[k_E]$ – element stiffness matrix, respecting:

$$[k]=(1+iG)\cdot[k_G]+i\sum G_E[k_E] \qquad (2)$$

Since the transient analysis doesn't include a calculation over the complex numbers, conversion of structural damping in equivalent viscous damping should be executed. The conversion is done using the complex damping matrix $[b_C]$ and dominant circular frequencies from the previous normal modes analysis:

$$[b_C]=[b]+\frac{G}{\omega^{*}}[k_G]+\frac{1}{\omega^{**}}\sum G_E[k_E] \qquad (3)$$

2. EXTREME REGULAR DYNAMICS SIMULATION

Perturbation (excitation) force function $F(t)$ is of impulse type. It is defined in this simulation on the basis of arbitrary

chosen mass of load m = 2650 kg on the maximal range of boom L = 45 m. Initial duration of the simulation is 50 seconds, after which there was sudden lowering of load at full speed of v = 20 m/min. So fast, seemingly uncontrolled lowering is performed because of the fastest lowering time of load on a given height. This is extreme regular situation with load which produces expressed dynamics without consequences.

For determination of the low of perturbation force caused by load, a rigid-kinetic mechanical model can be used. This model is created on the base of moment balance on shaft of the driving motor for hoist of load (D'Alamber's principle) [3]. The acceleration time of the driving mechanism and ropes during lowering of load (the perturbation force duration) is labeled with Δt_{II} (fig. 1). After achieving the full speed of lowering there was a sudden motor braking and stopping of load at the time Δt_{III} (the excitation force duration due to braking). So the load causes an extreme working dynamical impact on the frame supporting structure. In this way formulated, the model is approximate because it does not introduce an accurate curve of the motor excitation – but is used averaged (constant) excitation curve. Vibrations of construction are observed to the end of overall simulation time of 120 seconds.

Figure 1 shows equations of motion for load into four characteristic time intervals: I – suspension lifted load (Δt_I), II – acceleration (Δt_{II}), III - braking (Δt_{III}) and IV – calming after stopping (Δt_{IV}).

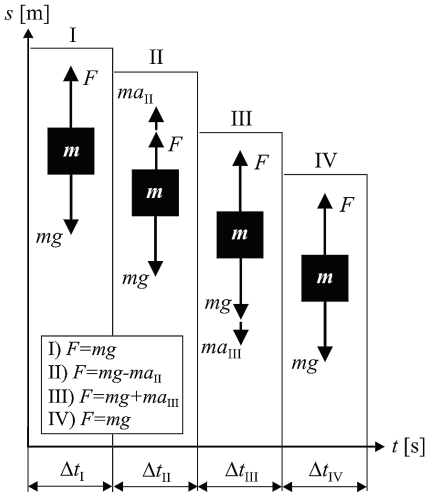


Fig. 1 *Excitation forces of motion for the four characteristic periods of lowering load*

For computing of the excitation force ΔF in function of acceleration and braking time, characteristics of lifting drive are needed. The selected drive (motor) KZK 200 L-6 has the following properties: P = 22 kW – power, M_n = 213 Nm – nominal moment, n = 985 min^{-1} – number of revolutions, I_r=0.6 kgm^2 - moment of inertia, v = 0.333 m/s – velocity of motion, η = 0.9 – degree of efficiency of transfer, ψ=1.7÷2.0 (adopted: ψ = 1.8) – median drive overload factor, P_{st}=11kW – motor power required to lift the nominal (static) load. Angular velocity of the driving motor amounts:

$$\omega = \frac{\pi n}{30} = \frac{985\pi}{30} = 103.15 \text{ s}^{-1} \qquad (4)$$

On the base of known characteristics of motor, the reduced moment of inertia of a rigid-kinetic model of drive can be calculated for the acceleration period (J_R) and braking period (J_R'), where $J_R' \approx J_R$:

$$J_R = 1.5 \cdot I_r + m \cdot \left(\frac{v}{\omega}\right)^2 \frac{1}{\eta} = 0.93 \text{ kgm}^2 \qquad (5)$$

Drive moment of acceleration M_A and static moments of load M_{st} and M_{st}' can be determined:

$$M_A = \psi \cdot M_n = 383 \text{ Nm} \qquad (6)$$

$$M_{st} = 9550 \frac{P_{st}}{n} = 107 \text{ Nm} \qquad (7)$$

$$M_{st}' = M_{st} \cdot \eta^2 = 86.67 \text{ Nm} \qquad (8)$$

On the base of these moments M_A, M_{st} i M_{st}' and braking moment M_B = 400 Nm the acceleration time Δt_{II} and braking time Δt_{III} are calculated in the load lowering regime (intervals II and III on fig. 1):

$$\Delta t_{II} = \frac{J_R \cdot \omega}{M_A + M_{st}} = 0.196 \text{ s} \qquad (9)$$

$$\Delta t_{III} = \frac{J_R' \cdot \omega}{M_B - M_{st}} = 0.306 \text{ s} \qquad (10)$$

Overall time of the transient situation (motion) amounts:

$$\Delta t_T = \Delta t_{II} + \Delta t_{III} = 0.502 \text{ s} \qquad (11)$$

and accelerations:

$$\Delta a_{II} = \frac{v}{\Delta t_{II}} = 1.699 \text{ m/s}^2 \qquad (12)$$

$$\Delta a_{III} = \frac{v}{\Delta t_{III}} = 1.088 \text{ m/s}^2 \qquad (13)$$

According to these accelerations a form of perturbation force F can be calculated. Standardized form of the force is shown on fig. 2. Two border relative accelerations with respect to gravity are:

$$\frac{\Delta F_{II}}{F} = \frac{(g - \Delta a_{II})}{g} = 0.827 \qquad (14)$$

$$\frac{\Delta F_{III}}{F} = \frac{(g + \Delta a_{III})}{g} = 1.111 \qquad (15)$$

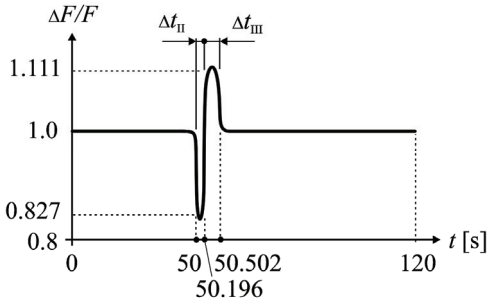


Fig. 2 *Impulse shape force of the extreme working regime*

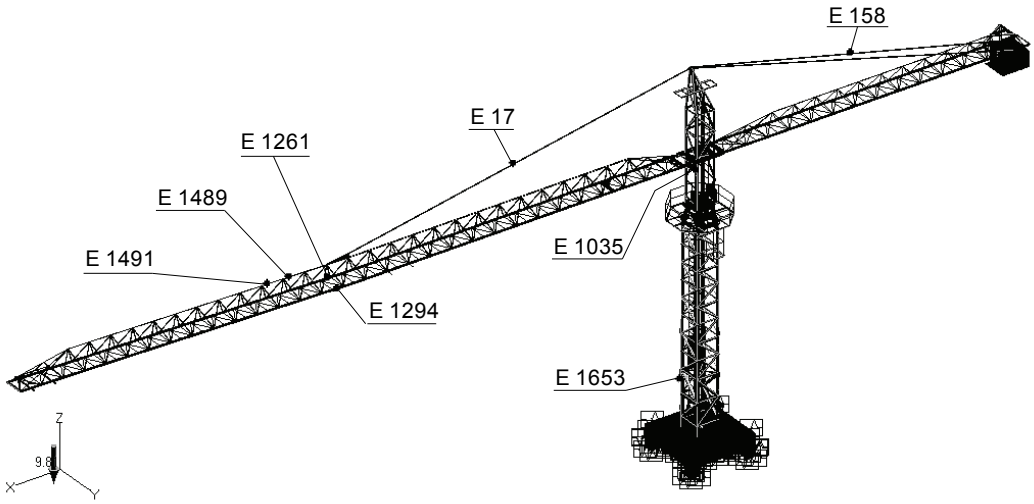


Fig. 3 *Positions of selected elements of a physical model of crane*

Using the dynamic equation of the mechanical system (1) with viscous damping (3) and solving the system of differential equations by one of the numerical integration methods, the structural response on an approximate given excitation can be found. By implementation of this transient analysis, the solutions are obtained in form of transient internal forces of the structure and node translations in time function. The extreme stress level of the steel structure is controlled by checking in regular dynamics (the excitation on fig. 2) on the crane boom structure. On that occasion, the extreme values of normal stress occur in the elements E-1261 and E-1491 and they are smaller than the limit:

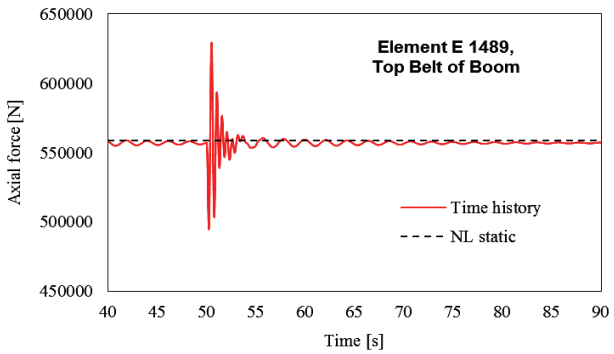
$$\left.\begin{aligned}\sigma_{max} &= \sigma_{max}^{E-1491} = 17.66 \ \ \text{kN/cm}^2 \\ |\sigma_{min}| &= \left|\sigma_{min}^{E-1261}\right| = |-11.21| \ \ \text{kN/cm}^2\end{aligned}\right\} < \sigma_{lim} = 30\,\text{kN/cm}^2 \quad (16)$$

Dynamical effect indicator in extreme working regimes is the dynamic coefficient K_D. This coefficient indicates the required dynamic reserve in elements of frame structure. On these supporting structures (lattice girders) the observation of axial forces in rods is interesting.

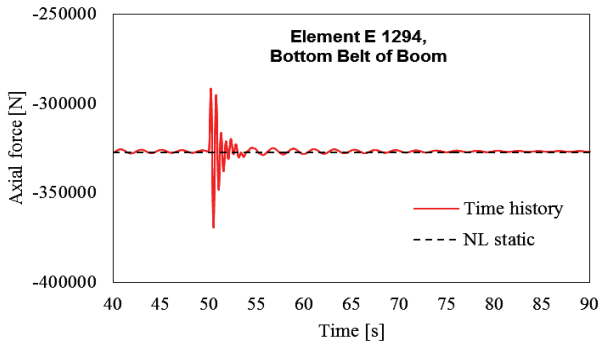
FEM model of the tower crane on fig. 3 is developed using the software MSC [1]. This model represents a representative and widely used frame structure [4]. In the modeling of structure, the BEAM and ROD finite elements are used. The dynamic coefficient K_D of elements in observed structure can be represented by ratio of the extreme axial force in the transient dynamics of regular regime $F_{D,\text{ext}}$ and the static axial force F_S (beam and rod axial force), respecting:

$$K_D = \frac{F_{D,ext}}{F_S} \quad (17)$$

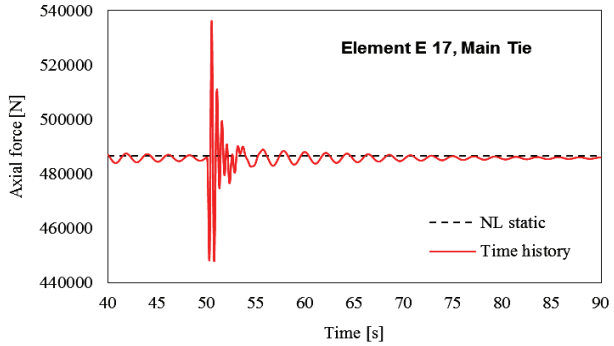
Static and dynamic axial forces can be pressure forces ($F_{\min}$) and tension forces ($F_{\max}$). By numerical simulation of a FEM crane model, the structural transient responses on effect of the excitation force in regular (working) regime are obtained. For the analysis of structure, the responsible elements are selected according to the following criteria:



a.



b.



c.

Fig. 4 *Axial forces of the extreme working regime (acceleration-braking) in selected members: a. top belt of boom, b. bottom belt of boom, c. main tie*

- Finite element type (beam and rod).
- Existence of significant difference (>10%) of the axial force intensity in transition in relation to statics (tower and boom elements).
- High absolute values of normal stress.
- Expected influence of position of a finite element in the structure on the change of force (elements of boom behind the main tie).
- In cases when a finite element represents separate unit (main tie, auxiliary tie).

The three finite elements are selected – representatives of the boom structure (top and bottom belt) and main tie. The change of axial force in these elements (E-1489, E-1294, E-17), during the perturbation of regular regime due to rapid lowering and sudden braking of load, is shown in fig. 4.

Dynamic coefficients for the elements in fig. 4 are determined by following expressions (respectively):

$$K_D^{E-1489} = \frac{F_{D,\max}}{F_S} = \frac{629243}{558991} = 1.126 \qquad (18)$$

$$K_D^{E-1294} = \frac{F_{D,\mathbf{min}}}{F_S} = \frac{-369262}{-327449} = 1.128 \qquad (19)$$

$$K_D^{E-17} = \frac{F_{D,\max}}{F_S} = \frac{536255}{486682} = 1.102 \qquad (20)$$

Table 1 contains data about axial forces in six selected finite elements of the structure shown in fig. 3. The comparative data are obtained by nonlinear static and transient numerical analysis (NASTRAN [5]). Looking at the table 1 and comparing the axial forces from transient analysis (time history) with forces from nonlinear static analysis (fig. 4) we can conclude the need for element dynamic reserve (i.e. structure) in extreme working regimes up to 19%. Recommended design values of the dynamic coefficient cover these extreme regimes of similar frame structures (K_D = 1.2).

Table 1 *Axial forces in selected members of the frame structure*

Finite element	Element type	Part of structure	Static analysis F_S [N]	Extreme working regime	
				Transient analysis $F_{D,\max\,(\min)}$ [N]	Dynamic coefficient $K_D=F_{D,\max\,(\min)}/F_S$
E 17	Rod	Main tie	486682	536255	1.102
E 158	Rod	Auxiliary tie	228485	257495	1.127
E 1035	Beam	Pylon	- 216458	- 247392	1.143
E 1294	Beam	Bottom belt of boom	- 327449	- 369262	1.128
E 1489	Beam	Top belt of boom	558991	629243	1.126
E 1653	Beam	Pylon	- 209097	- 249425	1.193

3. EXTREME INCIDENTAL DYNAMICS SIMULATION

Reliability of numerical model is best verified by experimental testing of dynamic characteristics of structure. Dynamic experimental testing of large transport machines requires good measuring conditions including quality measuring equipment. Incidental dynamic examinations of these structures are limited by risk of the damaging of structure.

In research [4] was performed the evaluation of accuracy of numerical model of tower crane, which is study subject in this paper. The investigation contained measurements of a certain number of dynamical behavior indicators of the crane structure (such as: micro-deformation, acceleration, change of force on the hook). On that occasion, the sizes of force on the hook, caused by lifting and sudden lowering of load at full speed until the impact on the ground, were measured by dynamometer. The standardized force diagram (fig. 5) on the basis of the measurement [4] will continue to be used for definition of the perturbation force in the transient numerical analysis of extreme incidental dynamics. The diagram covers the four characteristic time intervals:

- Lifting of load Δt_L = 10 s.
- Vibrations of lifted load Δt_{A1} = 55.93 s.
- Lowering of load at full velocity to shock on the ground ("overturn") Δt_S = 0.83 s.
- Amortization of structure vibrations after unloading Δt_{A2} = 53.24 s.

The trial load mass in the experiment was m = 2200 kg on the range L = 45 m. By numerical analysis was observed a transient situation caused by motion of slightly larger mass of load than in the experiment on same range, respecting m_T=2650 kg ($F = m_T g \cong 25997$ N).

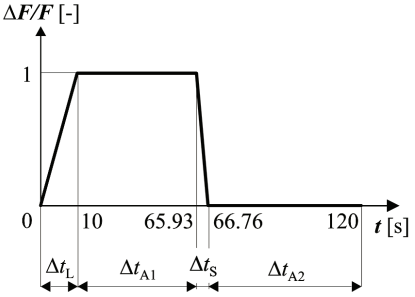


Fig. 5 *Change of standardized force on the hook in lifting and sudden lowering of load (to impact on ground)*

Table 2 also shows the function of relative perturbation force $\Delta F/F$ in relation to experimental time. This function represents a significant input data for setting the parameters of load in transient analysis.

Table 2 *Relative perturbation force in time function*

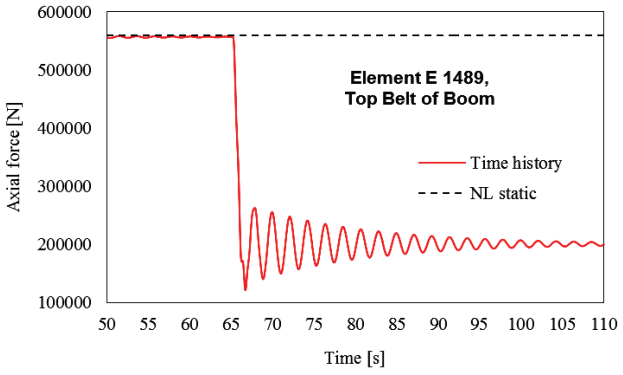
Time t [s]	0	10	65.93	66.76	120
Relative force $\Delta F/F$	0	1	1	0	0

Table 3 contains the values of dynamic axial forces in the four responsible members of the structure.

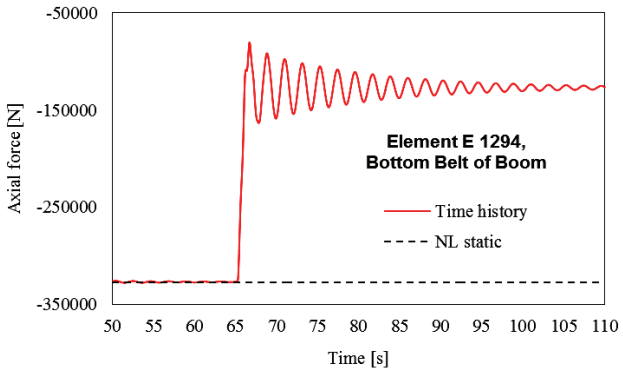
Table 3 *Axial forces in incidental regime*

Finite element	Part of structure	Axial force (transient analysis) $F_{D,\max\,(\min)}$ [N]
E 17	Main tie	347589
E 158	Auxiliary tie	261790
E 1294	Bottom belt of boom	- 163197
E 1489	Top belt of boom	262976

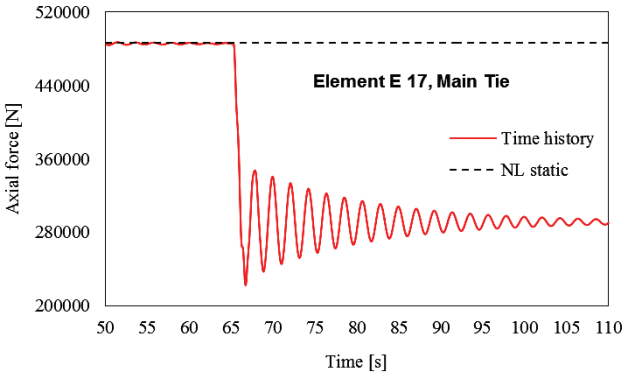
Figure 6 shows the change of axial force of incidental regime in same elements of structure considered in previous analysis of regular extreme dynamics (E-1489, E-1294, E-17).



a.



b.



c.

Fig. 6 *Axial forces of the incidental regime ("overturn" of load) in selected members: a. top belt of boom, b. bottom belt of boom, c. main tie*

The incidental dynamics, in relation to extreme regular regime, is different as follows:

- Strains in observed rods of the frame structure remain with the same sign after incident.
- Maximal dynamic axial forces in the belt rods of boom are with smaller intensity than forces of the extreme regular regime, respecting $|F_{INC}|:|F_{REG}|\approx 1:2.3$ (fig. 4 - a, b; fig. 6 – a, b).
- Maximal dynamic axial force in the main tie has smaller intensity than force of the regular regime, respecting $|F_{INC}| : |F_{REG}| \approx 1:1.5$ (fig. 4 – c; fig. 6 – c).
- Opposite situation is with forces in the auxiliary ties E-158 and E-159 (table 1 and table 3, $|F_{INC}| : |F_{REG}| \approx 1:0.98$).
- „Overturn" of load causes free damping vibrations of the structure with axial forces in rods where the average (finite) value is significantly different than the static value (because unloading).
- The incidental regime causes significant vertical translations. So, translations of the ending nodes (peak) of boom N-1409 and N-1410 (at max. range $L = 45$ m) amount $\Delta z_{N-1409} = 1184$ mm.

Different time on the abscissa of the extreme regular dynamics diagram (fig. 4) and incident dynamics diagram (fig. 6) is adapted for display of the most important time history of events. So, the initial period of simulations (fig. 4: $t<40$ s; fig. 6: $t<50$ s) isn't shown because it isn't especially interesting for the analysis. It is similar with the very finish of simulations. In both dynamic cases the overall time of simulation amounts $T_S = 120$ s.

4. CONCLUSION

The perturbation force of incidental regime makes significant change of dynamic state of the structure in the end of simulation in relation to the immediate state before the start of force effect. In constant compressed or tensed rods of the structure intensity of axial forces is reduced under the incidental excitation effect. This epilogue is even better from the standpoint of flexibility and stability. However, in some members of structure, a temporary change of the strain sign can occur. These cases follow the periods of expressed effect of perturbation force in incidental regimes. Some belt members of pylon structure of crane (e.g. elements E-1035 and E-1653 in fig. 3) can be exposed to temporary changing of strain (transition from pressure to tension and inversely). Besides the short-term perturbation force, the constant force of counter-weight has influence on that occurrence.

Another significant problem which the incidental dynamic analysis indicates, are long translations of structural nodes, particularly of those at the end of the crane boom. Translations in the global vertical direction are dominant. The maximal value of these translations (Δz_{max} = 1184 mm) indicates the area of great amplitudes.

Extreme regular regimes are characterized by extreme short-lasting dynamics after which the average dynamic force in rods reaches the same static value as before excitation. In other words, the dynamic axial force converges to the static value of the axial force after short-lasting effect of the perturbation force. Dynamic coefficients indicate satisfactorily dynamic reserve of the structure under the condition of correct system for control of the lifting/lowering velocity of load.

These investigations contribute to development of quality numerical FEM models of large frame structures. In the transient dynamical analyses of nonlinear systems where the numerical results can not be experimentally checked for many reasons, the model reliability is especially significant.

ACKNOWLEDGMENT

This paper is part of the project TR35049 at the University of Niš, Faculty of Mechanical Engineering, and was supported by the Ministry of Education and Science, Republic of Serbia.

REFERENCES

[1] MSC. Software Corporation, *MSC/Nastran V68 - Basic Dynamic Analysis*, http://www.mscsoftware.com, 2012.

[2] T. Rose, "An approach to properly account for structural damping, frequency - dependent stiffness / damping, and to use complex matrices in transient response", *Aerospace Conference and Technology Showcase*, 2001.

[3] R.M. Mijajlović, Z.M. Marinković and M.Lj. Jovanović, *Dynamics and optimization of cranes,* Monograph, University of Niš - Faculty of Mechanical Engineering, 2002, ISBN 86-80587-38-9.

[4] M. Jovanović, G. Radoičić, G. Petrović and D. Marković, "Dynamical models quality of truss supporting structures", *Facta Universitatis – Series Mechanical Engineering,* University of Niš, Vol. 9, No. 2, pp. 137-148, 2011.

[5] MSC NASTRAN, MSC. Software Corporation, Santa Ana, CA 92707, USA, www.mscsoftware.com, 2012.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

TSUNAMI – WATER SEISMIC WAVES

Slavko Zdravković[1], Dragan Zlatkov[2] Biljana Mladenović[2] Milovan Stanojev[3] Sandra Šaković[4]

[1] PhD, Full professor, Faculty of Civil Engineering and Architecture, University of Niš, Serbia,
[2] M.Sci, Assistant, Faculty of Civil Engineering and Architecture, University of Niš, Serbia
[3] PhD student, Faculty of Civil Engineering and Architecture, University of Niš, Serbia, milovan.stanojev@gmail.com
[4] Civil Engineer, The School of Higher Technical Professional Education, Niš, Serbia

Abstract - *The term ,,tsunami'' denotes instantaneous series of sea waves caused by the local changes of the ocean bottom elevation, i.e. heaving and settling of the ocean bottom and abrupt changes of volume of the sea basin caused by tectonic earthquakes. Such waves cause great destruction and casualties. Over 60% of them occur in the Pacific, and their prediction is very uncertain. According to their height, expect on the endangered coastline, evacuation of humans and animals to a safe distance is organized, which may amount to several tens of kilometers, while the waterfront width can be several hundreds of kilometers, which depends on the scale of wave intensity (I to VI). The wave height can amount to 30 and 40 m, so there are records of several hundred thousands of casualties and over a million of destroyed buildings. A specific case occurred in Japan on 11th March 2011 when the pumps of the nuclear power plant were flooded, damaged and failed to cool the nuclear fuel which caused immense environmental damage and human casualties, particularly in the Fukushima power plant. The rate of tsunami propagation depends on the ocean depth and is inversely proportional to the fourth degree.*

The most economical protection method is an international warning system in order to mitigate the risks for human lives, but not for the protection of material resources. Breakwaters, planting and densification of green belts proved to be suitable for reduction or cancellation of tsunami effects.

1. INTRODUCTION

The tsunami is actually a huge wave, caused by significant and abrupt changes in volume of the marine basin, which occur due to tectonic earthquakes or volcanic eruptions, and landslides in the accumulation basins along the coastline. Hitting the coast and sweeping all in front of it that is on its way from the land into the sea, this wave causes a great damage and destruction and many casualties. Tsunami waves reach up to 30 m in height. The heaving and settling of the ocean bottom during an earthquake is the main cause of generation of a tsunami. This phenomenon has been studied analytically and reproduced in the laboratory conditions (Wilson, WBB and Hendrrickson, 1962) [1]. The results of this study are consistent with observations of actual tsunami. It was found that the details of leading waves are sensitive to the shape and size of the disturbance and the rate at which the disorder occurs, so that both these characteristics can be derived from the wave records. Previous estimates (Ilda, 1936) have given higher values for the part of energy released during an earthquake, which could be related to the energy of tsunami.



Fig. 1 *Tokio earthquake on 19th March 2011, tsunami of hight 23 m*

This was due to lower estimated value of earthquake energy (Wilson, Webb and Hendrrickson, 1962). Reviewed calculations show that the percentage that can be converted into energy of tsunami is less than 1% in average, and that was never more than 2 % (Wilson et al, 1962, Van Dorn, 1965). It was found (Ilda, 1963) that, in order an earthquake could cause higher tsunami, the magnitude of these earthquakes must be greater than about 6.42 +0.017 *h*, where *h* is the focal depth in kilometers. Earthquakes beneath the ocean with a magnitude greater than 7.75 +0.08 h have often caused higher tsunamis.

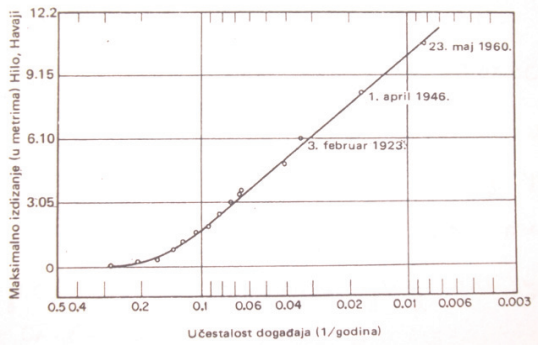


Fig. 2 *The frequency of maximum heaving of tsunami in Hilou, Hawaii, according to Wiegel (1964).*

Tsunami periods of 6 to 60 minutes correspond to significant tsunamis. Velocity of tsunami waves, depending on the length of the waves and the water depth is approximately defined by $\sqrt{gH}$, where g is the gravity acceleration, and H is the water depth, although the mathematical theory of

tsunami waves (Van Dorn, 1965) is far from simple. Given the enormous uncertainty about the theoretical aspects of the problem, it is reasonable to pay attention to the statistical evidence, if this is available. For example, the frequency of occurrence of maximum heaving of tsunami in Hilou, Hawaii, is calculated and shown in Fig. 2 (Wiegel, 1964). If this curve is adopted for future tsunamis in Hilou, the registered maximum will be exceeded, in average, once in T_S years, where T_S is the reciprocal of the corresponding abscissa. Assuming that the energy of the tsunami, and therefore the square of the maximum acceleration, in average, is proportional to the magnitude of the earthquake, it follows that in the wide domain, logarithm of the maximum heaving and the logarithm of the corresponding T_S must be approximately in linear relationship. The relative frequency of the occurrence in different oceans is as follows: about 62% of the known significant tsunami waves occurred in the Pacific Ocean, 20% in the Indian, 9% in the Mediterranean Sea, and 9% in the North Atlantic Ocean, while they are unknown in the South Atlantic Ocean.

2. EARTHQUAKE ON THE SEA BOTTOM

On the vulnerable banks, according to the height of the destructive wave, which is expected at that bank, and depending on time necessary to reach the bank, it is organized the withdrawal of people and livestock to a safe distance. It can amount to several tens of kilometers from the coast. Tsunamis exceed the total area of the oceans and seas, and their occurrence is limited by the thickness of the water mass. As with earthquakes on land and for excitation of water masses there is the scale of intensity used for its assessing. This scale consists of six degrees [2], whose brief descriptions are the following:

- Level I - seamless wave that is recorded only by instruments (mareographs)
- Level II - a noticeable wave;
- Level III - a wave that can break off ties of the small boat and cause some damage at the bank;
- Level IV - stronger wave - larger damage to coastal areas
- Level V - destructive wave;
- Level VI - catastrophic wave that completely destroys the coastal zone to a distance of several kilometers in interior.

Example of record of waves in the Pacific Ocean, during an earthquake at the ocean bottom is shown in Fig.3.

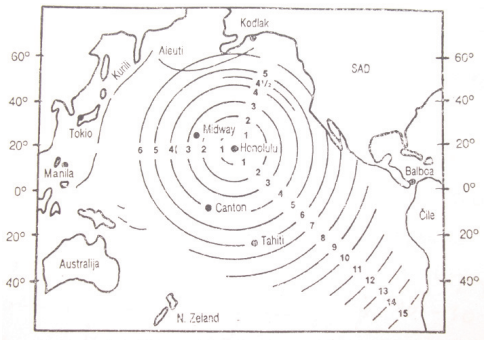


Fig. 3 *An earthquake at the ocean bottom near Hawaii, which has caused huge waves - tsunamis, whose movement is shown by curves and hours of travel, velocity was 700-800 km/h*

Tsunami waves occur at large peninsulas of epicenter area due to surface disturbance of the sea bottom, and they increase from the epicenter to the cost, so that can reach a height of 30 to 40 m (usually up to 10 m). The waterfront width along the coastline is more than 100 km, velocity 200 to 900km/h, usually 700 km/h, and the duration of waves (as they are in the series) are 10 to 30 minutes, and the largest occur in the Pacific Ocean.

During the earthquake in Indonesia in 2004 there were about 300 thousand casualties, most because of the tsunami, and in 2010 on Haiti 230 thousand people were killed, of which about 170,000 are drowned by the tsunami, and about 100,000 people remain homeless. Great number of casualties and damages were inflicted by tsunami waves during the following earthquakes: Lisbon in 1755, when waves came up to the Atlantic, in Messina in 1906, during the Tokyo earthquake in 1946. On 15th June 1896 on the island Honshu in the Pacific Ocean the huge tsunami waves up to 30 meters of height, in seven successive rushes, at the front width of several hundred kilometers, were wiped out about 10,000 houses, during which drowned about 30,000 people. Tsunamis used to appear in the Soviet Union, at the shores of Kamchatka and the Kuril Islands, during the earthquakes whose foci lied at the bottom of the Pacific Ocean (Fig. 3). Earthquakes followed by tsunami waves occurred in these areas in 1737, 1780, 1792, 1843, 1904, 1918, 1923, 1927, 1936, 1952 and later too. During the earthquake of 5th November 1952, the depth of the focus was about 30 km and its epicenter was at 140 km distance from the south coast of Kamchatka, magnitude M=7 degrees, engulfing the front width of about 700 km, wave height was between 6 and 15 meters, and they came to shore after 20 minutes.

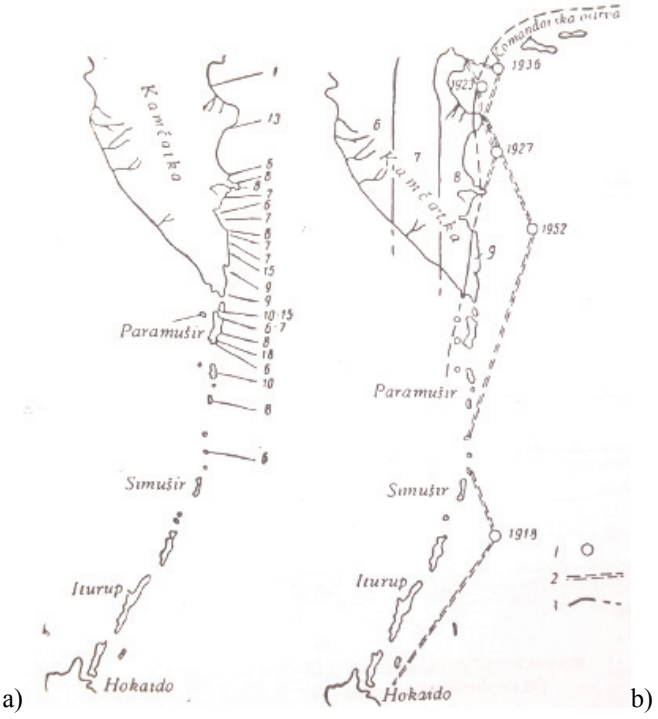


Fig. 4 *Kamchatka and Kuril Islands earthquake on 5th November 1952: a) height of tsunami waves on the banks, in meters; b) scheme of wave's propagation.*

The specific case was during the earthquake of 11th March 2011 in Japan (in the sea), M = 8.9º, where more than 20,000 people were killed, when the tsunami wave of height over 10m reached the coast in 10 minutes (Pacific Tsunami Warning Center has sent a message in 5 minutes) and damage the pumps of nuclear power plants, particularly on Fukushima, whose reactor was damaged that cause leaking of radioactive water into the sea, [3]. An area of 30 km from Fukushima was evacuated, food is radioactive at 70 km from the plant, and radioactive particles arrived to Serbia, 13000km far away. Consequences caused by these catastrophic tsunami waves were of the highest level, and their effect in the future is incalculable. If the pumps were placed 10 meters higher, probably this disaster would not have happened. The crisis in the Fukushima nuclear power plant was rated as the incident of highest (seventh) level of the scale of the International Atomic Energy Association (IAA). Nuclear power plants have withstood the effect of earthquake of magnitude M= 8.9 on the Richter scale, but the tsunami waves caused this catastrophe. During this earthquake energy released is 100 times greater than that of the Kobe earthquake from 17th January 1995, and 8000 times greater than the energy released after atomic bomb explosion over Hiroshima in 1945, and the damage is estimated at $ 300 billion.



Fig. 5 Fukushima during Japan earthquake of 11th March 2011, tsunami of height 14 m.

Tsunami wave propagation velocity depends on the depth of the ocean, and can be determined by use of the following formula [4]:

$$V = \sqrt{gH\left(1-\frac{\eta}{H}\right)} \tag{1}$$

where H is is the depth of the ocean, η is the tsunami wave height, and g is acceleration of gravity. Tsunami wave's velocity is proportional to the depth of the sea, so that across the shallower regions the tsunami is moving more slowly. Reducing velocity and depth of the sea lead to a large and rapid increase in height of the tsunami waves, since the wave that comes from the ocean, has a higher velocity. Ratio of the tsunami waves heights η_1 and η_2 is approximately inversely proportional to the fourth root of the ratio H_1/H_2, i.e.:

$$\frac{\eta_2}{\eta_1} = \sqrt[4]{\frac{H_1}{H_2}} \tag{2}$$

In addition to the depth of an ocean, tsunami wave's height is influenced by specific shape and other characteristics of riparian line.

Bays which are getting narrow in the shape of funnel influence the tsunami wave height to increase, while wide bays that closed narrow pass have the opposite effect. Energy of tsunami, as noted above, and therefore the square of maximum wave acceleration, in average, is proportional to the magnitude of the earthquake. Coast directly facing the epicenter usually suffers the highest heaving of the waves, and the waves increase coming closer to the island so that they are largest on the coast, as happened during the Japanese earthquake, as well.

Numerical examples of calculation of tsunami wave height for three different cases of ratio H_1/H_2 are the following:

1st case: $\eta_2 = 0.75m,\ H_1 = 2.5m,\ H_2 = 5000.0m$

$$\frac{0.75}{\eta_1} = \sqrt[4]{\frac{2.5}{5000}} = 0.15 \Rightarrow \eta_1 = 5m$$

2nd case: $\eta_2 = 1.0m,\ H_1 = 0.6m,\ H_2 = 80.0m$

$$\frac{1.0}{\eta_1} = \sqrt[4]{\frac{0.6}{80}} = 0.067 \Rightarrow \eta_1 = 15m$$

3rd case: $\eta_2 = 0.3m,\ H_1 = 0.6m,\ H_2 = 80.0m$

$$\frac{0.3}{\eta_1} = \sqrt[4]{\frac{0.6}{80}} = 0.201 \Rightarrow \eta_1 = 15m$$

In addition to depth, the height of waves depends on relief too. There are three categories of coastal zone relief that affect the level of threat to the site as follows:

- adverse form of riparian zones, spacious low shore and large shallows, so it is difficult to find a harmless sections for the construction of buildings and human habitat;
- midle type of relief where it slopes down to the sea in the form of terraces dangerous for any building, and human settlements can be built only on the high parts of the coast;
- favorable terrain is high coast where the ocean reaches great depths inaccessible for tsunami waves.

3. PROTECTION AGAINST TSUNAMI WAVES

We will describe the measures that have been applied successfully to limit the devastation caused by the tsunami waves. International warning system is the most appropriate measure to reduce impacts on human life from the tsunami waves, although it does not protect material resources, [5]. It was observed that sometimes it took a few hours (Fig. 3) that tsunami crossed the Pacific. Thanks to this, it was possible that the inhabitants of coastal settlements, such as in Hawaii or Japan, receive in time notification from the Pacific Tsunami Warning Center, about the wave which occurred on the coast of Chile, and even about the order of its magnitude, so many lives were saved by the evacuation of the population of coastal cities.



Fig.6 *GITEWS (German-Indonesian system of early warning of tsunami)*

Other ways of protection are construction of breakwater, shown in Fig.7, and also planting and densification of greenery are sometimes found convenient to reduce or cancel the effects of the tsunami waves. Since the amplitude of the oscillations in estuary is function of their natural vibration period, the measures conducted for the purpose of changing natural vibration periods of waves in order to achieve more favorable conditions also can be effective.

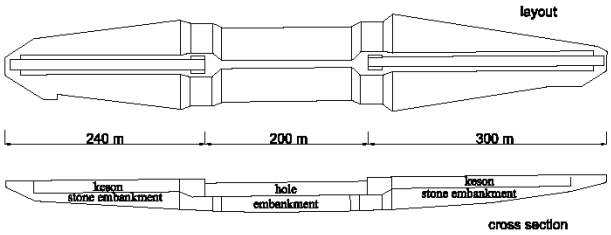


Fig. 7 *Breakwater for protection against tsunami waves, Horikawa*

4. CONCLUSION

Tsunami waves are caused by abrupt changes of marine basins that occur most often due to tectonic earthquakes, i.e. when it comes to heaving and settling of the ocean bottom or to any significant change of bottom relief. Such waves cause great destruction and casualties. This phenomenon has been studied analytically and modeled in laboratory conditions, and the results are in good agreement with observations of actual tsunami. From 1 to 2 percents of earthquake energy is converted into the energy of tsunami. Velocity of tsunami waves, depending on the length of the waves and the water depth is approximately defined by $\sqrt{gH}$, where g is the gravity acceleration, and H is the water depth. Over 60% of them occur in the Pacific, while they are unknown in the South Atlantic. According to their height, expected on the endangered coastline, evacuation of humans and animals to a safe distance is organized, which may amount to several tens of kilometers, while the waterfront width can be several hundreds of kilometers, which depends on the scale of wave intensity (I to VI). The wave propagation across the Pacific Ocean during an earthquake on the ocean bottom near Hawaii is shown in Fig.2, from which can be seen that these waves traveled for several hours to the coast and their velocity was between 700 and 800 km/h, which is usually the case. Thanks to that it is possible in coastal areas in time to inform people, to organize evacuation to a safer that is higher location, to save human lives, while there is no rescue for facilities during strong tsunami waves.

Tsunamis that have caused huge number of casualties, over 100 thousand, and destroyed over one million buildings, are listed in the paper.

The specific case was during the earthquake of 11th March 2011 in Japan (in the sea), M = 8.9º, where more than 20,000 people were killed, when the tsunami waves of height over 10m reached the coast in 10 minutes (Pacific Tsunami Warning Center has sent a message in 5 minutes) and damage the pumps of nuclear power plants, particularly on Fukushima. Its reactor was damaged that cause leaking of radioactive water into the sea, [3]. An area of 30 km from Fukushima was evacuated, food is radioactive at 70 km from the plant, and radioactive particles arrived to Serbia, 13000km far away.

The correlation between ratio of tsunami waves heights η_1 and η_2 and ratio of ocean depths H_1 and H_2 is shown by the numerical examples. In addition to these ratios, the height of the tsunami waves depends on the specific shape and properties of riparian lines, so there is: adverse form of the coastal zone, the middle type of the terrain and unfavorable terrain.

Regarding protection against tsunami waves, breakwaters, planting and densification of green belts proved to be suitable for reduction or cancellation of tsunami effects. The most economical protection method is an international warning system in order to mitigate the risks for human lives, but not for the protection of material resources.

ACKNOWLEDGEMENT: *This research is conducted at Faculty of Civil Engineering and Architecture of University of Niš in the framework of the project in the field of technological development in the period 2011-2014, and titled Experimental and theoretical investigation of frames and plates with semi-rigid connections from the view of the second order theory and stability analysis (TR 36016), financially supported by the Ministry of Education, Science and Technological Develpment of the Republic of Serbia.*

REFERENCES

[1] Newmark/Rosenblueth, *Osnovi zemljotresnog inženjerstva*, IRO „Građevinska knjiga'', Beograd, 1987

[2] B. Sikošek, *Zemljotres i ja*, Eksportpres, Beograd, 1986

[3] S. Zdravković, B. Mladenović, D. Turnić, *Nuclear facilities safety,* XXV Kongres DIMK, Tara, 19-21. X 2011, pp. 319-326

[4] S. V. Medvedev, *Inženjerska seizmologija,* Građevinska knjiga, Beograd, 1965

[5] S. Zdravković, B. Mladenović, D. Zlatkov, *Seismic safety of the equipment of nuclear power plants,* The 16th Conference of the Man and Working Environment, FOS, Niš, 27-28. X 2011, pp. 273-277

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

CHARACTERISTIC SOURCES OF SEISMIC VIBRATIONS

Tomislav Igić[1], Slavko Zdravković[1], Biljana Mladenović[1], Predrag Petronijević[1], Sandra Šaković[2]

[1] University of Niš, the Faculty of Civil Engineering and Architecture, mbiba@gaf.ni.ac.rs
[2] University of Niš, High Technical School

Abstract - *The paper, after the introduction with general characteristics of composition of Earth crust under the oceans and the continents, describes origin of earthquakes. Since the specific gravity of the soil from the surface to the center of the Earth increases, the continental granite plates appear to float on the batholite. The scale of magnetic polarity indicates that the continents move 1 to 6 cm a year and more (figure 1), which means that 200 thousand years ago the continents did not exist in present form. The main role in formulation of, for now, accepted theory of tectonic plates which is explained in the paper (1960) was played by hard and soft properties of the Earth's crust (lithosphere and asthenosphere), even though there are still some unanswered questions about how earthquakes are generated. One of the most acceptable mechanisms for explanation of emergence of earthquakes originates from Royd.*

The most active is the Pacific ring where around 60% of all earthquakes occur, which amounts to 80% of total seismic energy. The polarity magnetism scale indicates that most of continental drift occurs in this area. The earthquake origin mechanisms have been explained according to seismic, geological, seismo-tectonic and other parameters of soil properties, local soil properties and friction among continental plates.

1. INTRODUCTION

The composition and structure of the Earth's crust beneath the oceans are not the same in relation to the continents. Under the ocean lies basalt, a heavy and hard black rock, with high content of iron and magnesium. Beneath the basalt there is a layer similar to basalt, but heavier. In many places the basalt pours out on the ocean floor in the form of lava, forming a volcanic cone. Many to these cups are islands. Unlike the basalt the stones constituting continents are more light-weight, lighter in color and contain more silicon and aluminum. The rocks on the continents can be different, but their composition is similar to the granites. That is why we say that the continents consist of granite and bottom of the ocean from basalt. The difference in specific gravity of these two types of rocks accounts for the continents rising above the oceanic depressions. The density of granite is 2,65 t/m^3 and of heavier basalt 3.30 t/m^3. In this sense, the continents, as granite plates float on the basalt, and these assumptions were made 350 years ago, while they were scientifically explained after 1950, after examination of magnetic polarity of the rocks on the bottom of the Atlantic ocean. It is known that matter heated over 600˚C loses magnetism, which is restored when it is cooled down. In the fifties, particularly during the International year of physics, there were multiple geophysical researches. Each time when the magnetic field of the Earth changes, there is a new zone differing in polarity of the grains of magnetic minerals in the Earths crust. The scale of magnetic polarity indicates that the crust in the western part of the Atlantic moves towards northeast at the speed of 1-2cm/yr. With mean velocity of 1.5cm/year, the Atlantic ocean would expand 1500km in 100 million years, and there are evidences that it did not exist 150 to 200 million years ago. The velocity of movement in the Indian ocean is more than 3cm/yr., and in some parts of the Pacific 6cm/yr and more. In this sense, it is evident that the parts of the Earth's crust are in motion. Not only the continents drift, but the plates of the Earth crust 50-1000km thick on which the continents float [1].

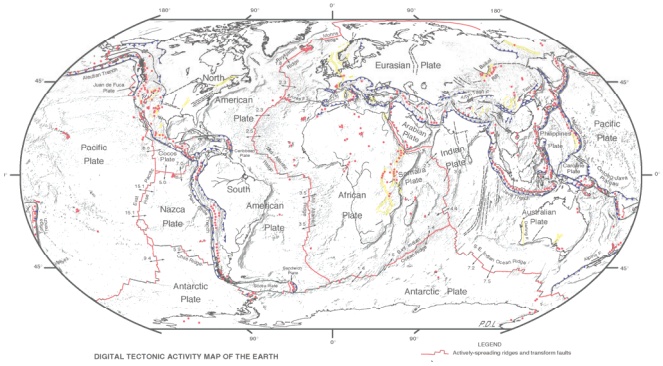


Fig. 1 *Tectonic activity map of the earth [1]*

The Earth's crust is at some places destroyed and compressed, and new compression zones are created, manifested as narrow zones or belts determined by three elements. Instability of these zones is confirmed by the fact that almost all the folds and deepest earthquakes are created in this zoned. Deformations inside the plates can be ignored in the area with deformation movements at the edges of the plates. This gave rise to the theory of plate tectonics (Le Pishon et all 1973), as a „unified working hypothesis proves the kinematic model of the upper layers of the Earth ". In case one plate slides under the other, it becomes seismically active. At small depths of up to 70km, the earthquakes occur on the surface of the part between two plates along the entire contact of the plates, especially if those are continental plates. At greater depths, sometimes even below 700km. The focus of the earthquake is in the zone 20-50km, which marks the center of the plate which is drawn near. The study of the

phenomenon of these earthquakes [2] indicates that they are generated according to the stresses of pressure or separation which are oriented along the plate rim (Isacs and Molner 1971).

Such considerations explain the best the gravitational sinking of the lithosphere. The most probable cause of plate movement is the energy whose source is interior heat which is released in the area of oceanic trenches. It is assumed that the process takes place in the earth's mantle. There are six main tectonic plates (Figure 1): Pacific, American, Indian, African, Eurasian and Antarctic. Except those, there are smaller plates: Cocos, Caribbean, Arabian, Philippine, Somali and others.

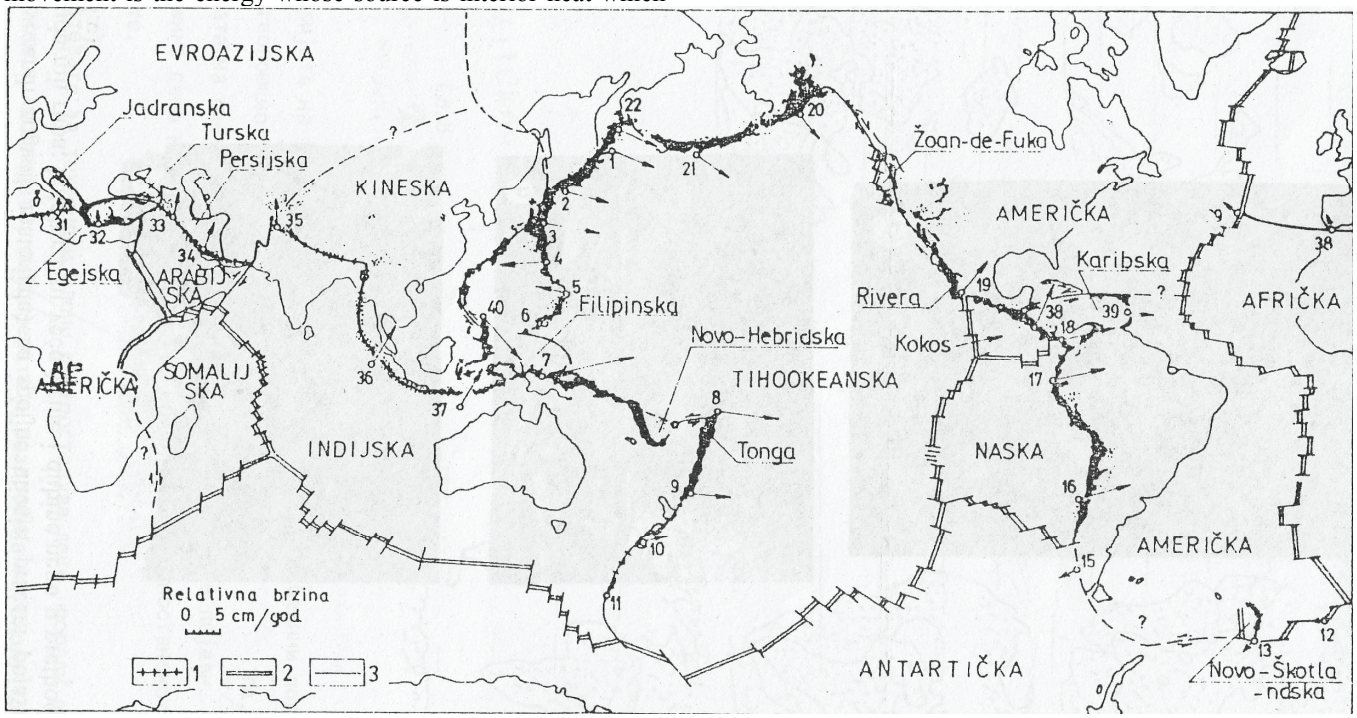


Fig. 2 *The relative moving speed of plates*

Figure 2 presents relative boundaries of tectonic plates and their relative speeds of movement. Practically 99% of all earthquakes is related to plates boundaries.

2. ORIGIN OF EARTHQUAKES

Under the action of interior and in part external forces which result from the energy sources, which are steady, certain parts of the earths crust are subjected to constant pressures, deformations and movements. The property of the earth's crust and its upper part, (lithosphere and astenosphere) is that it is composed of hard and soft parts which played a major role in formation of the new theory of plate tectonics. This theory of origin of earthquakes was developed in the 60's, the it included the idea of continental drift by German scientist A. Wegener in 1912 [3]. The tectonic plate theory strives the unify the data of geological development of the Earth, its magnetic field, ocean floor topography, seismological and other phenomena. The tectonic movement mechanism is explained in the following way. The shallow part beneath the ocean floor constantly rises, which causes its cooling and increase of its hardness. This section exerts pressure on the earlier cooled part of lithosphere, causing it to drift from the location where it was formed. It then collides with the plate on the other side, subduction of one plate under another occurs, and the plate sinks into hotter parts of the mantle. This motion (flow) of the parts of lithosphere is a consequence of movement of mantle material and outer core in the Earths crust, with Conrad's (15km), Mohorovicic's and Gutenberg discontinuity at 2898km. K. E. Bullen in 1940 determined the average density of the Conrad's granite layer 2,65 g/cm3, and of the Mohorovicic's basalt layer 2,87 g/cm3. The mean earth's density is 5,5179 g/cm3. The image which can be observed along the rim of tectonic plates, overally corresponds to the results of earthquake research. However, some questions remain unanswered such as the shape and size of the plates, the speed of their movement etc. Yet, this picture indicates on possible mechanism which leads to increase of energy in the confined space of the earth, and thus to earthquakes, which is an element the older theories lack. Confronting African and European plate cause earthquakes in the Mediterranean, and thus in our parts. Though, all the influences on the mechanism of their emergence are yet unknown. The lithosphere is divided into a certain number of plates of various sizes. Basically, nowadays three types of earthquake causes can be differed, regarding the tectonic plates. Origin of earthquake in the Vroncea focus (Romania) is the consequence of subduction of Easteuropean tropoform under the Carpathian mountains. Yet, yearly more than 75% of seismic energy is released by shallow earthquakes h<60km, and for this reason the shallow earthquakes represent a great danger for the Balkan Peninsula and other regions where the earthquakes occur not along the boundaries but inside the continental parts of tectonic plates. These earthquakes occur as a consequence of a much more complex tectonic structure in them. There is a very complex tectonic picture in this area, as a consequence of disintegration of lithosphere to different

forms, and microwaves of various composition and various dynamical causes in long geological history. The territory of the Balkan Peninsula represents one of the geologically most complex structures, with intensive dynamic and anomalous geophysical fields, as a result of uneven and constant separation and division of tectonic plates and other small structures in the Earth's crust, and deeper in the ground or areas where large mechanical stresses are accumulated as constant process. One of the most acceptable mechanisms to explain the origin of earthquakes comes from (H. F. Reid, 1910), who studied the earthquake of 18th June1906, in San Francisco, USA.

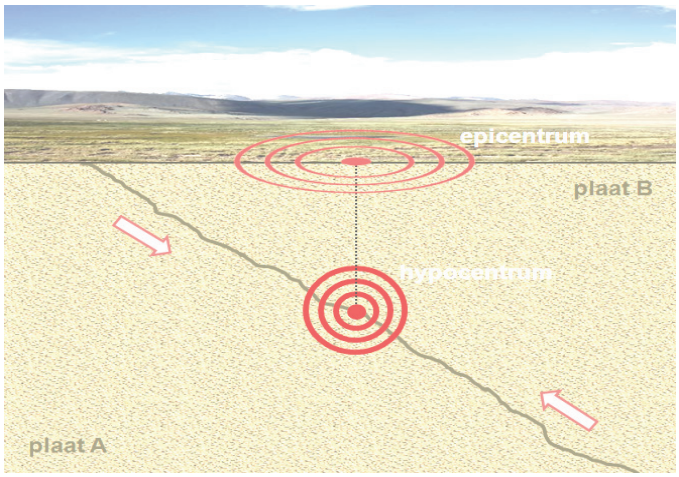


Fig. 3 *Epicenter-hypocenter-schema*

The location where the failure – rift occurs (which is always under the surface) is called the hypocenter and its projection on the surface epicenter, who, regardless of their name should not be assumed to be points. Their dimensions are several tens of kilometers, and in comparison to Earths size can for some purposes be presented as points. Therefore the rift in the hypocenter does not occur because of the earthquake, but vice versa, the earthquake is the consequence of the splitting in the hypocenter. It is more accurate to say the area of an earthquake focus. Therefore, the hypocenter of an earthquake is place inside the Earth where the sudden release of energy starts, which is called the epicenter on the surface of the Earth.

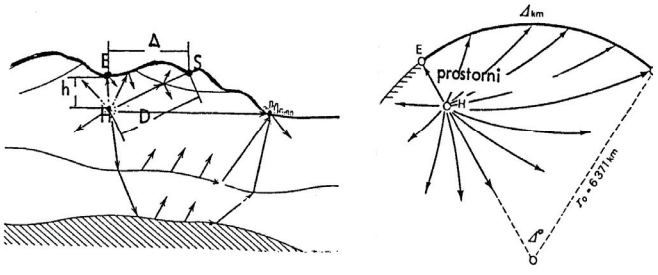


Fig. 4 *Epicenter-hypocenter-schema [3]*

3. GEOGRAPHIC DISTRIBUTION OF EARTHQUAKES

The most active area is the Pacific ring, where around 60% of all earthquakes occur, which amounts to around 80% of total seismic energy [4]. This ring starts near the Kuril islands, includes the southeast part of Kamchatka, and then over Aleutian islands continues onto the western hemisphere and travels along Alaska, Pacific coast, all the way down to Mexico. Various parts of this ring have various frequencies and various intensities of earthquake. The most frequent and most intensive earthquakes occur in the Caribbean and Aleutian islands. In the area of Alaska they are relatively weak, then their intensity decreases towards California, and increases in California and remains high to the Mexican coast. The Mediterranean or TransAsian ring expands to the eastern parts of Asia across Pamir, then goes further to the west across Iran, including the Black and Mediterranean basins, and goes further to the Atlantic ocean to the area of the Azores. Around 15% of total seismic energy is released in this zone, which will be presented in the following example. The approximate relation of the magnitudes [5] and various energy sources is:

- For earthquake of magnitude; M=6.0-6.9, energy is $0.9 \cdot 10^{13}$-$1.32 \cdot 10^{14}$J, quantity of TNT: 2.13-31.5kt, or number of atomic bombs 0.107-1.57(AB), intensity I=VII°-VIII° modif. Merkali.
- For earthquake of magnitude; M=8.0-8.9, energy is $0.9 \cdot 10^{16}$-$1.32 \cdot 10^{17}$J, quantity of TNT: 2.13-3.15Mt, or number of atomic bombs 107.15-1571.4(AB), intensity I=XI°-XII° modif. Merkali.

The most intensive and most frequent earthquakes in this ring occur along the mountain ranges. The ring starts in Spain, then continues across the Alps and the Apennines then proceeds across the southern part of the Balkans, Carpathians, descends to Crete and on to Asia Minor. The most active parts of this ring are along the coasts of Spain, Southern Italy, Greece and Asia Minor, along with Cyprus and Corfu. Also seismically active are Romania and Bulgaria (which have nuclear power plants). If the seismic rings are scrutinized, the rifts can be observed in them. Their maximum depth, mutual position of epicenters for deep and shallow earthquakes and characteristics of their inter-connectedness directly depend on the geological and geophysical properties of the area. [3].

Deep earthquakes occur in areas where geological material descends. For this reason, these areas are often called "the descending blocks of lithosphere" and others are called the Genof zones. The most of deep earthquakes occur around the Pacific, and the deepest one occurred under the Flores sea at the depth of 720km. Outside the Pacific basin, earthquakes deeper than 100 km are not frequent, with the exception of the eastern part of the Mediterranean, Romania and southern foothills of the Himalayas where earthquakes 220 km deep were registered [1]. In the Balkan Peninsula the pass of Corinth has been known since ancient times for huge earthquake catastrophes. In the west, it touches the group of Ionian islands, which have also been known since ancient times for their frequent earthquake catastrophes, and in the east, there is the Aegean archipelago, where earthquakes almost never cease. The seismicity of this influences not only the seismicity of Greece, but of former Yugoslavian countries, Albania and Bulgaria. Particularly huge catastrophes were the earthquakes in Skopje, Banja Luka, Kopaonik and Montenegrin coast that caused huge material damage. Intensive economic development and intensive construction in the conditions of seismic activity increases

the seismic risk. This led to intensification of all the researches in the field of seismology which are aimed at reduction of human lives and material property loss. Nowadays, and earthquake does not represent an unknown phenomenon. It is considered a phenomenon which inevitably accompanies development of Earth, occurring on those surfaces where there are sudden large-scale movements and they are explained by sudden release of a large quantity energy, which sends the shock ways through the rock mass of the Earth's crust.

4. SEISMICAL PROCESSES MODELS

In order to understand the earthquakes and consequences they have on the soil, buildings and people, we must know their origin, that is the sources of the forces causing them, and also the material structures on which the forces act. The earthquakes of tectonic origin are the most frequent, and the science studying these forces and their action is called tectonics (gr. Tekton – builder). The influence of the regional seismic characteristics on the terrain is determined on the basis of the research:

- Seismic characteristic of the terrain
- Geological (non-tectonic) characteristics,
- Seismo-tectonic characteristics of terrain.

These researches include terrain in the radius of 100-150 km around the considered location, which includes the local, adjacent and distance seismic zones which affect the location in seismic terms. On the basis of the obtained results of the mentioned researches, the following parameters are obtained:

- Seismotectonic characteristics of terrain
- Seismic action on the bedrock.

Definition of seismic characteristics of terrain includes research and definition:

- Of parameters of manifestation and potential in a seismological zone
- Maximum occurred and maximum expected magnitude of earthquake (M_{max})
- Parameters of the earthquake frequency

$$\log N = a_1 + b_1 M \quad (1)$$

- Parameters of microseismologic field

$$Ii = a_2 M - b_2 \log \sqrt{R_e^{\,2} + h_i^{\,2}} + C_i \quad (2)$$

Parameters of intensity of seismic action

On the basis of mentioned seismic characteristics of terrain, the values of representative seismologic parameters which are used to determine seismic action on the bedrock are defined, which are as a rule:

Maximum magnitude of the earthquake, epicenter or hypocenter distance, stagnation of seismic action, frequency of the earthquake and assumption of the seismic focus mechanism, i.e. mechanism of release of energy accumulated during elastic deformations, i.e. mechanism of generation of seismic waves.

Influence of local seismo-geological characteristics of terrain are determine on the basis of: geotechnical and engineering seismological characteristic of terrain, and which are determined on the basis of the following researches:

- Local seismo-tectonic activity of the considered location;
- Engineering geological characteristics of location;
- Hydrogeological characteristics of location;
- Geomechanical characteristics of earth material;
- Geophysical (seismic and geoelectric) properties of earth layers;
- Characteristics of microseismological disturbance of soil
- Position and parameters of bedrock.

Parameters of regional and local characteristics of terrain and own characteristics of building structures can be grouped in four factor groups [4] which reflect the soil behavior those being:

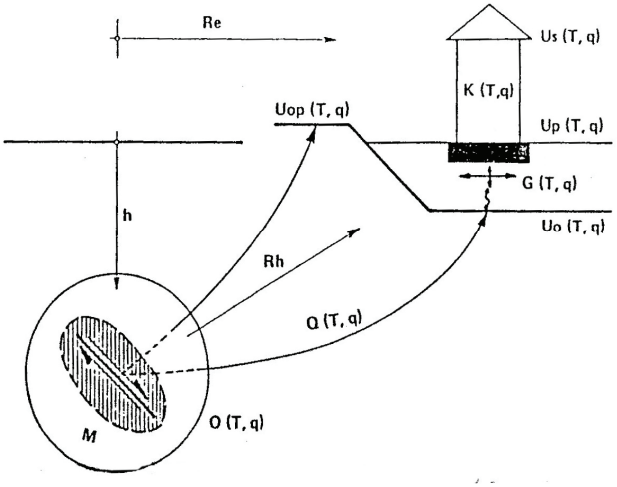


Fig. 5 *Engineering seismologic model [4]*

$O(T)$ - parameters of seismicity of terrain and focus of the earthquake;

$Q(T,q)$ - parameters and tectonic and physic mechanical anisotropy of terrain;

$G(T,q)$ - local seismologic parameters of terrain;

$K(T,q)$ - own parameters of building structures.

The mentioned parameters are schematically displayed in figure 5 which presents the basic engineering seismological model with basic parametric elements from which depends the intensity and characteristics of seismic action of an earthquake. In figure 5 the symbols Us(T,q); Up(T,q) and Uo(T,q) mark the characters of seismic action of the earthquake on the building structure, surface of the terrain and the bedrock of the terrain, and the symbols in the figure read:

M – magnitude of an earthquake

E – energy released in focus

h – depth of focus

Re – epicenter distance

Rh – hypocenter distance

T,q – frequency characteristics of dampening of seismic waves and vibrations in bedrock, terrain surface and on the engineering structures.

In general case the mentioned parameters can be presented by the following expression:

$$U_p(T,q) = F\left[Q(T);Q(T,q);G(T,q)\right] \quad (3)$$

While seismic regime whose main characteristics consistently repeat in case of the earthquakes in seismic zones and according to the laws of seismic activity of terrain, are determined in space, time and energy parameters of terrain seismicity, the magnitudes and mechanisms of releasing of seismic energy in the focus of the earthquake are determined by the initial amplitude and frequency composition of generated seismic waves in seismic foci.

The generated seismic waves in the process of propagation through the earth's crust, from the focus to the considered location on the surface of the soil are subjected to amplitude and frequency modifications which are consequences of exhausting of their energy. In this, there is stagnation and change of frequency composition of seismic waves, which affects and gives the characteristic form to the parameters of seismic action on the bedrock.

Most of the energy released in the earthquake is used to movement of rock masses and their collapse in the vicinity of the rift, as well as on heating up of those materials. Fortunately only a fraction of this energy spreads as seismic waves as described. This energy causes soil movement and damage to the buildings, so it is called the energy of seismic wave E. There are different empirical formulae used for calculation of dependence between the seismic wave energy and earthquake magnitude M, the Gutenberg and Richter ones being the most used:

$$\log_{10} E = 4.8 + 1.5M \quad (4)$$

Energy of seismic wave (or shorter: seismic energy) is calculated in Joules. From the last expression, it is clear that the value of magnitude M is only rough estimate, so the error made in the process has a large impact on the value of seismic energy. In average, the annual energy of all earthquakes which occur in the world is between 10^{18}J and 10^{19}J [2].

It happens that the new rifts emerge during earthquake, which provided grounds to claim that the rifts are not the causes of the earthquake but their consequence. Mechanical destruction of rocks starts in the weakest spot. This spot is the focus, which is usually at a considerable depth. The speed at which the failure travels from the focus is lower than the speed of seismic waves, because of which the maximum shock precedes the dislocation of surface soil [3].

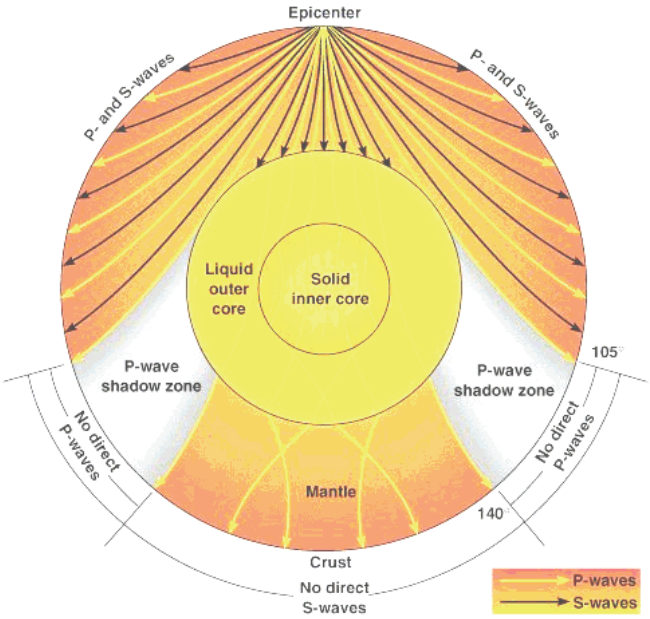


Fig. 6 *Movement of P and S waves*

The depth of an earthquake is from several to 700 km. Going deeper under the surface, we may notice the temperature and pressure rising. The increase of pressure leads to the increase of friction force, which opposes the movement on the rifts, and the simultaneous increase of temperature facilitates deformations and flow of rocks. If the rocks are not strong enough, they cannot accumulate sufficient energy of elastic stress, which is sufficient to overcome the friction force. Because of this formation of the rift over the failure is possible only for shallow earthquakes. Three types of tests confirmed the correctness of elastic shock theory. The first type is related to the image in the focus of the earthquake, on the basis of movements of the surface. If it is assumed that the source of the earthquake, that is, focus of the earthquake is in the center of the sphere, and connect the focus of the earthquake to the station on the Earth's surface, the line which represents the trajectory of (P) waves, they will intersect in different points. In laboratory, it was determined that the fluid present in the pores acts as lubricator in the crevices and does not allow them to close. American army, in 1962 injected toxic gasses in the drill holes to the depth of 3.5km. And even though since 1882 to that moment there were no earthquakes, since 1965 there have been around 700 earthquakes whose frequency was directly related to the quantity of water.

5. CONCLUSION

The source of seismic vibrations are hypocenters, or foci of earthquakes in the earth's crust, most often at the depths between 5 and 60km (shallow focus) or rare, at the depths of 300 to 700 km under the surface (deep focus). Hypocenters of various earthquakes in former Yugoslavia were found at depths up to 30 km. the epicenter is the projection of hypocenter on the earth's surface. These two concepts should be only conditionally comprised as fixed points, because all these events occur along some lines or surfaces so of the term hypocentral and epicentral areas is used. When talking about strong earthquakes, the nine degree (1-8.9) Richter scale is applied (S. F. Richter-USA 1935). Its measure is estimation of the intensity of the earthquake as the amount of released energy in the hypocenter and it is called the magnitude (M), and it is related to the released energy by the equation 2. Earthquakes are related to compression and extension of the Earth's crust, caused by physical activities taking place deep inside the Earth [6], [7]. The earth crust is broken into many smaller and larger piece, on seams filled with soft material with the enormous energy of elastic energy. When these break and there is abrupt relative movement between the mentioned blocks, the energy is released. The blocks can move in different ways. The process by which the seams break, that is, by which the rocks mass tears is called the hypocenter or the focus of the earthquake. Earthquakes are one of the manifestations of tectonic activity of the earth's crust, that is vertical vibration movement caused by deep earthquakes. These processes of primary tectonics are manifested on the surface of the earth mostly in the form of mechanical movements of heaving of the surface, creating of folds and occurrence of earthquakes. Processes which occur in the earth's crust are essentially explained, and it is supposed that density can increase up to 18%, so linear deformations of material may be as much as 6%. The source mechanism of earthquakes is based on tearing of earth's crust continuity [6]. Our knowledge of causes and conditions of emergence of earthquakes are still hypothetical and approximate, so they can be developed as a theory of tectonic plates. The basic property of earth's crust and its upper part (lithosphere and astenosphere) is to have hard and soft parts, which played a major role in formation of new "theory of global tectonics", that is, Theory of tectonic plates, developed in 1962. In the paper is explained mechanism of tectonic plates movement. The scale of magnetic polarity shows that the plates move at various speeds from 1 to 6 cm and more. In case one plate is subducted under the other, it becomes seismically active. Rifts are formed at the places where there is relative movement of the rock mass , and the earthquakes occur only on active rifts. The kinetic energy which is generated at cracking of rock mass propagates in the form of seismic waves in the surrounding. Through the interior of the earth there are spatial waves which are divided into P primary longitudinal and S – secondary transversal waves. The spatial waves are limited only to the surface of the Earth and those are R (Riley and L (Lave's) waves. The earthquakes most often occur in Pacific ocean, around 60% expending 80% of energy. A lot of energy is released in the area of tehe Mediterranean and the parts of the Balkan peninsula which of the seismically active area. The seismic waves, that is mechanism of generation and occurrence of earthquakes with all the causes, and in which whey they are caused.

Acknowledgement: This research is conducted at The Faculty of Civil Engineering and Architecture of University of Niš in the framework of the projects in the field of technological development in the period 2011-2014, and titled "Experimental and theoretical investigation of frames and plates with semi-rigid connections from the view of the second order theory and stability analysis" (TR 36016) and "Development and improvement of methods for analyses of soil-structure interaction based on theoretical and experimental research " (TR 36028), financially supported by the Ministry of Education, Science and Technological Develpment of the Republic of Serbia.

REFERENCES

[1] S. Ivanović, Inženjerska seizmologija, autorizovana predavanja univerzitet "Veljko Vlahović", Titograd, građevinski fakultet, 1986.

[2] S. Ivanović, *Zemljotresi – fenomeni prirode*, Univerzitet „Veljko Vlahović", Titograd, 1991.

[3] D. Hadžievski, *Opšta seizmologija*, IZIIS, Univerzitet „Kiril i Metodij", Skoplje, 1985.

[4] M. Stojković, *Inženjerska seizmologija I,* IZIIS, Univerzitet „Kiril i Metodij", Skoplje, 1988.

[5] B. Skošek, *Zemljotres i ja,* EX PORTRESS, Beograd, 1986.

[6] S. V. Medvedev, *Inžinjerska seizmologia,* Građevinska knjiga Beograd 1965.

[7] M. Milićević, S. Zdravković, *Dinamika Konstrukcija*, univerzitet u Nišu, 1984.

[8] B. Petrović, *Odabrana poglavlja iz seizmološkog inženjerstvaI,* IRO; Građevinska knjiga Beograd, 1985.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

BRONTIDES - ACOUSTIC PHENOMENA DURING EARTHQUAKES

Milovan Stanojev, Slavko Zdravković, Dragan Zlatkov

Faculty of Civil Engineering and Architecture, University of Niš, Serbia, milovan.stanojev@gmail.com

Abstract - *The paper discusses „brontides“ an acoustic phenomenon occurring during earthquakes, which have not been paid due attention in contemporary seismology. It is a phenomenon accompanying earthquakes, scaled to degrees by Knett and Sleberg, from very weak, weak, moderate, strong to very strong brontidee. This term „brontide“ is called „bramidos“ in Mexico, „huceni“ in Slovakia, „mistpefers“ in the Netherlands and Belgium, and „rombo“, „marina“ or „balza“ in Italy.*

For instance, during the earthquake in Tibet in 1950, the sounds resembling cannonades were heard at a distance of 1200 km. Regarding that earthquakes occur along the fault lines of blocks pressing one against another, with lot of irregular surfaces, bulges, depressions, in the contact zone there is a certain resistance – friction, which, when released, gives rise to earthquakes. The seismic energy released in the process propagates as longitudinal, transversal and surface waves, whereby different acoustic phenomena occur, from the rustle of the leaves to the large explosion, as of a high caliber artillery shell.

1. INTRODUCTION

Wide variety of sounds almost always occurs during earthquake and these sounds are called brontides. During the earthquake it comes to releasing of enormous seismic energy, for example, at the magnitude of M = 6.0 to 6.9 degrees on the Richter scale or intensity of 8-9 ° on MCS-64 scale, the energy released is from $6x10^{13}$ to $8x10^{14}$ J (joules), or such as Đerdap I to work for 2 years and 9 months, or to explode from 0.71 to 10.5 bombs like dropped on Hiroshima. At magnitude 8.0 to 8.9 degrees on the Richter scale, or intensity of 12 degrees on the MCS-64 scale, the energy released amounts from $6x10^{16}$ to $8,8x10^{17}$ J , or such as Đerdap I to operate 1740 years, or to explode 714.3 to 10,470 atomic bombs dropped over Hiroshima [1]. As the Earth's crust consists of several (6 to 22) tectonic plates, rubbing of these plates at the seams leads to the appearance of a variety of sounds (usually rumble) from a variety of causes, and such a huge seismic energy to be released. In addition to ground shaking and waving, and all that is on it, the stage at which earthquakes occur abounds with various sound and light effects, what understandably causes all living beings to be aghast. Today earthquakes are not the unknown, but also not completely understood and explained phenomenon. As there are natural and artificial (technogenic) earthquakes, the former are negligible in comparison to natural, especially to tectonic ones that represent 85% of all earthquakes, during which more than 90% of the total seismic energy is released. The largest number of earthquakes, about 60%, occurs in the Pacific Ocean, with the energy released up to 80% of the total. A certain amount of huge seismic energy is spent on the occurrence of tsunami waves (1 to 2%), where their appearance is possible, and a certain amount of seismic energy appears in the form of acoustic energy. The results of this energy, which can not be prevented, are the acoustic trauma - lesions and neurosis of extra adductive etiology [2].

Brontide is a noise, i.e. sound that disturbs, upsets and destroys particularly psycho-physiological functions of the organs of the human body, because an earthquake itself is terrible occurrence. In a strict sense, the noise is only a subjective expression of a physical phenomenon, in this case, all phenomena related to the earthquake, which there are many, starting from the occurrence of an earthquake in focus, fireplace or hypocenter. Realistically, sound is not noise until the man or animals appear, who are disturbed by that sounds. Fireplace of an earthquake is not a point but the line or area of tens of kilometers, but can be considered in some cases as the point of the same rupture regarding the size of the Earth. Rupture surfaces along which plates are leaned each to other, of course, are not smooth. There are a lot of irregularities, bulges and depressions. Besides, the rock material is not everywhere of the same strength. All this causes in the contact zone of the two blocks to appear a certain resistance – friction, which causes them to be suspended until the stresses disrupt this balance, and the blocks are moved. Energy released in the area where the friction is overpowered “radiates” in all directions, in the form of seismic waves that when reach the surface cause its shaking.

From the hypocentre in Earth's interior to its projections on the surface of the Earth - the epicenter, the waves do not go straight but cut rocks, there is reflection and refraction, and other phenomena when brontides occur - sounds resembling distant or near drumming, cracking of wood, cannon shot or big explosion. It should be borne in mind primarily the fear that is caused by an earthquake as a natural phenomenon. Overall sound is of interest to many scientific disciplines - from engineering to medical and sociological ones. In the field of engineering disciplines three aspects of interest in sound, such as a physical phenomenon, are dominated: the sound as a means of communication, as a tool and as a noise. Sound like a tool involves the use of sound energy to detect the occurrence of an event by “tapping” of source that generates sound, like the sound appearance during the earthquake, i.e. brontides. Very often the sounds by their actions may disturb and threaten the man and his health.

The changes in position of particles due to the presence of sound that is time-variable mechanical disorders, are sound vibrations. These vibrations are accompanied by the changes

of pressure and density of elastic medium around equilibrium positions of its particles, as it is the case during earthquake. Noise is in reference with the most commonly used definition, any unwanted sound. Noise, therefore, has the same physical characteristics as well as sound, and it differs because it causes a variety of psycho-physiological sensations. Noise is sound that disturbs, upsets or damages the physical and psycho-physiological functions of the organs of the human body. In real terms, the noise is just a subjective experience of sound as physical phenomena. In fact, the sound becomes noise only when there is an individual who is disturbed by that sound. Due to action of an earthquake every sound can be treated as noise because it disturbs-upsets. The use of the term emission of noise is defined by standards such as the capability of a source to generate noise, which can not be fully applied to brontides - the sound caused by the earthquake. Sound vibrations, i.e. sound during earthquake occur under the influence of internal force, which takes the particles of elastic-plastic medium from the equilibrium position at the junction of two tectonic plates (two blocks) and encourages them to move together, in which case the seismic waves are generated. Sound waves - brontides as elements of the seismic waves are:

- Longitudinal - longitudinal waves, which are characterized by alternating compression and stretching of particles of matter in the direction of the wave's motion. These are the fastest waves that first reach the Earth's surface, moving at a speed of 7 to 8 km/sec [3].
- Transverse - transverse seismic waves are characterized by oscillating of particles of matter around the equilibrium position perpendicular to the direction of the waves. Propagation velocity of these waves is 4 to 4.5 km / sec.
- Surface (Rayleigh's R and Love's-s L) seismic waves are generated at the free surface of an elastic body, in this case the Earth's surface. R and L waves are predominantly vertical and horizontal in direction, respectively. Speed of their propagation is different and depends on the structure of the Earth's crust [4]. They are moving at speed from 0.2 km/sec (through the humus soil) to 5.6 km/sec (through the granite) and have elliptical orbits and are performed in the horizontal plane, perpendicular to the direction of wave propagation.

There is deflection, i.e. abrupt change in the direction of propagation of these waves when they reach an obstacle or discontinuity of medium (Konrad's, Mohorovič's or Gutenberg's discontinuity) which is one of the reasons for the appearance of seismic sound waves – brontides.

2. SOUND PHENOMENA ACCOMPANYING EARTHQUAKES

In addition to the main effects, such as shaking, there are related frightening phenomena, which also contribute to the fact that earthquakes cause the fear of the population and anxiety of animals in even greater degree than usual. These side effects are reduced to light and sound effects.

Particular impression, however, gives rise to various sounds that almost always accompany strong earthquake from rumble similar to artillery cannon to the rustle of the leaves. Practically, they occur throughout the whole sound field (from 16 to 20 000 Hz), as well as in the domains of infrasound (lower frequency than 16 Hz) and ultrasound (frequencies greater than 20000 Hz).

Changes in sound pressure are in most cases small compared with the equilibrium values, that is static pressure. The static component of pressure in the air under normal conditions amounts of 100 kPa. At a frequency of 1000 Hz, the highest limit of sound that the human sense can register is $2x10^{-5}$ Pa. Measurements showed that marked changes in pressure corresponds to moving of the molecule in free air space during the acoustic oscillations of $7.7 x10^{-12}$ m. Rounding this result, it is concluded that the sensitivity limits of the human sense of hearing means the movement of molecules in free space on the order of 10^{-11} m. In order to get an impression of this size, one can make a comparison with the dimensions of micro particles. It is well known that the diameter of the hydrogen atom, which has the smallest atom in nature, is $1.04 x10^{-10}$ m.

During the earthquake, except for the sounds and smells are those physical phenomena which can arouse the animals to behave strangely. It is assumed that the small tremors that precede the main earthquake, can unleash large amounts of gases of different smells from the soil, and sounds that the human sense of hearing can not register, while the animals and birds can, for example, fish, sharks, snakes, pigeons, dogs and others.

Table 1 *Scale of 5 degrees to determine brontides*

Degree	Manifestation
1^0	*Very weak brontide*: In the free space can barely be heard, and indoors is not heard at all. Noise close to the ground is like a faint sound of wind, the rustling of leaves, the gentle flow and distant drumming.
2^0	*Weak brontide*: In the free space is clearly heard while indoors barely. It sounds like a thump, poor drumming, rain falling, tearing of fabric or dishes breaking.
3^0	*Moderate brontide*: It is heard indoors as muffled drumming, sometimes sounds like a wave hitting the sea shore, trees sagging under the strong wind or the wind howling through the chimney. Moderate brontide can be replaced with a remote explosion or sound of timber tearing.
4^0	*Strong brontide*: It sounds like a strong throbbing or thunder, shock of big wave at the bank, demolishing of walls, strong rain showers, tearing of balvan, drop of heavy objects or cannon shot.
5^0	*Very strong brontide*: It is characterized by strong roar and thunder shot. Sounds like shock of waves on the shore during a storm, the demolition of large blocks of rock, roaring of hurricanes, intense steaming from the boiler, high caliber artillery shell hits, and the big explosions.

In Tibet, during earthquake in 1950, the sound was heard resembling cannon fire similar to that of the Second World War, at a distance of 1200 km. Professor Jelenko Mihajlovic has studied them on the island of Hvar and analyzed

statistically two series of brontides even of weak earthquakes in the period from 20th June 1937 to 24th August 1938, and of 19th July 1940 to 11th March 1941. In the first series recorded were 2278 brontides and 148 weaker earthquakes, and in the second one 2628 brontides and 133 earthquakes. In various parts of the world this sound phenomenon is call differently. In Mexico they are called "bramidos", in India cannons from Barisal" because they were very strong during earthquake in the town of Barisal. In Slovakia, they are called „huceni". In the Netherlands and Belgium, where these phenomena are generally very rare, however, there is a name „mistpefers". In Italy there are different names for them: „rombo", „marina" or „balza"

Scale of 5 degrees to determine brontides (Knett J., A. Sieberg), is shown in Table 1.

Brontides appearance today, however, is not studied intensively, so this scale is somewhat out of date, because the sound effects can be measured by instruments as well as by precious barographs because they are associated with changes in atmospheric pressure [1].

3. BRONTIDEI IN PAST EARTHQUAKES

On the southern coast of the Gulf of Corinth in 373 BC there were two thriving towns, Helika and Bura. Helika was located at the mouth of the river Eufusia that descended to the north towards the Gulf of Corinth from the Peloponnesian Heights. It was in full swing of development. Bura was located about 15 km southwest of Helika and about 12 miles south of sea coast. This town was as prosperous as Helika and served as an example of economic and cultural development to other cities, and even Corinth. The winter days in 373 BC, 403 years after the first Olympic Games, nothing unusual has happened. It was cold and, toothy sun warmed during the day as every winter. The only strange thing was that mice and rats were running out from the stone houses to the streets in large numbers, not frightened by passers who persecuted them. But at that time of the year, that was not anything unusual. But before the dawn vicious roar was heard from the depths of the ground that was followed by earthquake. Rumble and wind noise poured into hellish symphony which was joined by a frightened screams of the population, suddenly woken up from a peaceful sleep by this disaster. Rumble was increasingly intensified and reached its hellish scale tones accompanied by tearing and splitting of the ground. Wide and deep cracks were opened in which tumbled houses with all the tenants in them. In a few minutes the whole town Helika located at the bottom of the cracks, crushed, along with the population. During this time the population of the Bura survived the same horrific minutes. The ground on which the town stood began to crack accompanied by rumble and hell wind noise. Among the numerous intertwined cracks that have opened up more, the houses and residents collapsed. Only it was not the cold waves of the sea, to fulfill this terrible tomb, because it occurred 12 miles off the coast.

In 1883 happened to be one of the world's greatest disasters. With a tremendous explosion that could be heard thousands of miles away, half of the island of Krakatoa sank into the Pacific. This small island between Java and Sumatra in Indonesia was halved on 27th August. At 13 o'clock a series of explosions began which shook the ground. At 14 o'clock the new smoke above the volcano crater, reaching a height of 25 km and obscuring the sun, so that in the radius of 75 km around the volcano for a full 52 hours was a dark night. Volcanic activity continued, and the flashes of explosions and thick darkness are alternately rotated. This, however, was only a prelude to cataclysm. The main explosion occurred on 27 August in 22 o'clock and 2 minutes. Then it disappeared 27 km^2 of Krakatoa Island in emptied magmatic chamber. Sea filled the gaping hole in eddies, and the explosion that followed the apocalypse could be heard at more than 5000 miles away. At the nearby islands many people were killed by falling rocks and a hot shower of ash. The greatest havoc, however, caused a huge tsunami waves, which are raging across the island Krakatoa and claimed more than 36,000 lives. Destroyed were, partially or totally, 295 towns and villages.

In 1908 earthquake destroyed the city Messina on Sicily. Houses, towers, fences were destroyed. It was a dark night and a tremendous rumble and roar that accompanied the shaking of ground, were horrible. Frightened residents who managed to get out of the demolished buildings flocked to the port, thinking that they would be safer, but without hope, because the waves were reaching a height of 5.4m in Messina Bay and 4.8m on the Italian side. People on the coast were affected and dragged away to the open sea, where most drowned. Balance of the accident was terrible: the 100,000 people were killed, and the total causalities of 180,000. It is estimated that the earthquake in Messina destroyed 98% of the houses.

On 29th February 1960 in the Moroccan city of Agadir, all the animals were disturbed. Many people that night could not fall asleep, because in the houses strange creaking and cracking was heard. Under Agadir, two faults "awoke" strong sources of seismic energy. Shock lasted about 10 seconds. Motion of the soil, however, was terrible, 1.2 meters elevated and moved to the side. Destroyed were 70% of the houses, and 12,000 people were killed.

Alaska earthquake in 1964 was the strongest in North America, when the earth shook without any prior notification. Rumbling and shaking lasted about 4 minutes.

4. CONCLUSION

Today earthquakes are not the unknown, but also not completely understood and explained phenomenon. Earthquakes occur along the fault lines of blocks pressing one against another, which are not smooth. There are a lot of irregular surfaces, bulges, depressions, and even rock material strength is not the same everywhere. All this causes there is a certain resistance – friction in the contact zone. When the balance is disturbed and blocks moved, energy released "radiates" in all directions, in the form of seismic waves which reflects and refracts from the hypocenter to the surface of the Earth, passing through the soil of the different characteristics, and then also other phenomena occur. For these reasons brontides occur, sound phenomena classified in the scale of 5 degrees, where:

- 1^0 is very weak brontide, which sounds like a faint sound of wind, the rustling of leaves, the gentle flow and distant drumming;

- 2^0 is weak brontide, which sounds like a thump, poor drumming, rain falling, tearing of fabric or dishes breaking;
- 3^0 is moderate brontide, which sometimes sounds like a wave hitting the sea shore, wind howling timber tearing;
- 4^0 is strong brontide, which sounds like a strong throbbing or thunder, demolishing of walls, tearing of balvan, or cannon shot;
- 5^0 Very strong brontide, which sounds like rumbling and cracking during thunder, the demolition of large blocks of rock, roaring of hurricanes, high caliber artillery shell hits, and the big explosions.

Towns of and Helika and Bura, in 373 BC were completely destroyed. The insidious roar and wind noise that woke people was heard. Rumble increasingly was intensified and reached scale of hellish tones accompanied by tearing and splitting of the Earth. In the 1883 Krakatoa Island sank in the Pacific, after a tremendous explosion of the volcano and the explosion was heard over 5 000 km away. In 1908 the city of Messina in Sicily was destroyed (98%). It was a dark night and a tremendous rumble and roar accompanying the earthquake, were horrible. The number of victims amounted to 180 thousand people.

In 1960, 29 February, in Agadir in Morocco animals were disturbed, while people could not go to sleep because of the strange creaking and cracking in houses was heard. The earthquake lasted just 10 seconds, but due to the uplift of ground of 1.2 m, 70% of the houses were destroyed and 12,000 people were killed.

During the earthquake in Alaska in 1964, without previous shaking, the ground was rumbling and shacking for about four minutes.

ACKNOWLEDGEMENT: *This research is conducted at Faculty of Civil Engineering and Architecture of University of Niš in the framework of the project in the field of technological development in the period 2011-2014, and titled Experimental and theoretical investigation of frames and plates with semi-rigid connections from the view of the second order theory and stability analysis (TR 36016), financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.*

REFERENCES

[1] B. Sikošek, *Zemljotres i ja*, Eksportpres, Beograd, 1986

[2] D. Cvetković, M. Praščević, *Buka i vibracije*, Univerzitet u Nišu, Fakultet zaštite na radu, Niš, 2005

[3] M. Milićević, S. Zdravković, *Dinamika konstrukcija,* Univerzitet u Nišu, Niš, 1984

[4] S. Ivanović, *Inženjerska seizmologija – autorizovana skripta,* Univerzitet „Veljko Vlahović'', Građevinski fakultet, Titograd, 1986

[5] D. Hadžijevski, *Opšta seizmologija,* IZIIS, Univerzitet „Kiril i Metodij'', Skoplje, 1985

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

VIBRATION OF SEISMIC WAVES TROUGH SOIL

Dragan Zlatkov[1], *Slavko Zdravković*[1], *Nikola Romić*[1]

[1] Univerzitet u Nišu, Građevinsko – aritektonski fakultet, Srbija, s.zdravkovic@gaf.ni.ac.rs

Abstract - *This paper presents the vibrations of longitudinal P, transverse S and surface L and R (Love and Rayleigh) waves. It has been shown that longitudinal waves are the fastest and that they first reach the Earth's surface. They are followed by transverse and surface waves. The surface waves possess the greatest energy and cause the greatest damage to the constructions. All of these waves are not as nearly accurate and it's the cause of this is the oscillatory movement which is irregular in the sense of its direction, amplitude, acceleration, period, etc., which can be concluded from seismic records, as with every earthquake, a seismic field is created with an extremely tangled image of oscillations-vibrations. With the increase of distance from the station to the epicenter, the intensity and clarity of P waves decrease, only to become at the distance from 103 to 142 an obscure area. Based on Dalembert's principle, the wave equation is induced by using Laplace's operator and Lame's constants, with the use of Yung's shearing model and Poison's coefficient by applying the operation rot. The paper also presents reflections and refraction of P and S waves, and Rayleigh waves, as well as the fact that the acceleration of Love waves is a function of frequency.*

1. INTRODUCTION

Seismic waves which are generated by earthquakes can be divided into three basic groups: longitudinal, transverse and circular surface waves (L-waves, Rayleigh waves and Love waves). Longitudinal waves, also referred to as primary waves, P-waves (indac primae) are waves the movement of which is characterized by the alternation of addition and stretching of the matter in the same direction as the wave travels. These are the fastest waves that reach the Earth's surface and they travel at velocity from 7 to 8 km/Sec (1).

Transverse, secondary S (undae secundae) waves are represented by the particle's oscillations around the balanced position, 90 degrees to the direction of the wave model. The propagation velocity of these waves ranges from 4 to 4.5 km/Sec.

Circular surface waves, Rayleigh (R) and Love (L) waves, are transverse surface waves. They are generated at the free surface of the elastic body, in this case, the Earth's surface. They resemble the gravitational waves on the surface of water generated under the activity of the wind. This type of seismic waves propagates in two dimensions, and with the distance from the epicenter, they have more dominant significance. Their propagation velocity varies and depends on the structure of the Earth's crust. They travel at velocities ranging from 0.2km/se (humus) to 5.6km/se (granite).

Seismic waves recorded by the adequate instruments on the Earth's surface are not as nearly regular as it would be expected, regarding the mentioned description of seismic waves. Namely, the records show that it is an oscillatory movement which is irregular in view of direction, amplitude, acceleration, period, etc. This is a result of the seismic waves travelling through layers with different properties, reflection of the waves in the crevices and the boundary surfaces between the layers, the addition of basic and reflected waves and alike. Relatively small amplitudes and relatively shorter periods characterize the starting section of the record. This is a result of the impact of the longitudinal waves. The farther the epicenter is, the longer is this interval. The middle section of the record shows the largest amplitudes and represents the focal point of an earthquake. The transition from initial to middle section of the record is always clearly marked [2].

2. SEISMIC WAVES

The energy produced in the hearth of an earthquake spreads in all directions in the form of elastic waves which are called seismic waves. As already mentioned, various seismic waves, different in their specific properties of propagation through different media in the Earth's crust, reach the Earth's surface. Basically, there are three types of seismic waves: longitudinal, transverse and surface waves, longitudinal, primary, P-waves

These waves represent the fast alternating change of the pressure and dilution of the matter with the change of its volume. Longitudinal "P" wave resembles the sound wave. When passing through the rocks, each of its article moves back and forth in the direction of the wave movement. Thus, a rock endures more compression and decompression (figure 1), the same amount of pressure as if it were hit by a hammer on one of its ends.

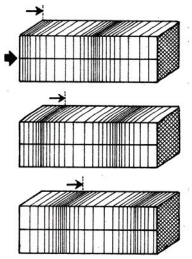


Figure 1: *The oscilation of particles goes back and forth in the direction of the wave movement*

The particles exposed to a strike for a moment move forward and the return backward thus transferring exertion to the neighboring particles coercing them to move rightwards. Once the impulse reaches the opposing end, his reach is similar to the bouncing of a little ball hang on a rock. These waves have the greatest speed when they erupt on the Earth's surface. Longitudinal or "T" waves travel through both solid and liquid layers of the Earth's crust, transverse, secondary, "S" waves

These waves deform the medium they are travelling through but they do not change its volume. When the "S" wave travels through, the particles move orthogonally to the direction of the wave propagation, thus resembling a rope tied to one end and held by at the other end (figure 2).

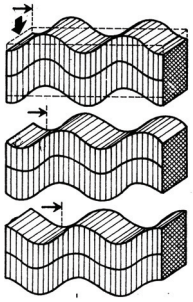


Figure 2: *The scheme of propagation of transverse waves*

That means that "P" wave always travels first, and that "S" wave is late. The farther from the hearth the recorder (seismograph) is, the greater the period between the arrival of the "p" and "S" waves. If we record the time of arrival of "S" and "P" waves, then we can easily determine how far the epicenter is (figure 3)

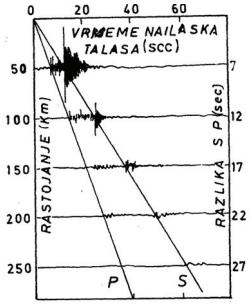


Figure 3: *Time dependency of the time of arrival of "P" wave and "S" wave on the distance from the hearth of the earthquake*

Surface waves. The waves that travel through the Earth's inner parts are followed by surface waves which travel along the Earth's surface at the speed ranging from 0.2 to 5.6km/Sec. There are two types of surface waves, Love and Rayleigh waves. Surface waves are formed on a free surface of the solid, elastic space, similarly to gravitational waves on the surface of any liquid under the impact of wind. Surface waves usually occupy the most intensive section of a record (they cause the largest damages). They are also referred to as "L" waves or long waves as the period of their oscillation is greater than one of "P" and "S" waves.

Love waves (figure 4) are transverse oscillation similar to those of "S" waves, but their difference is that they are formed only on a horizontal plane.

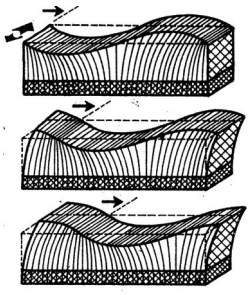


Figure 4. *Love waves*

They travel along the Earth's surface, constantly deflecting from the lower and the upper limit of surface layers. They do not have vertical components. Rayleigh waves have a significant vertical component. With them, the strike in the direction of the wave expansion travels first, and then, the oscillation is carried out up and down, where new strike is being formed (figure 5).

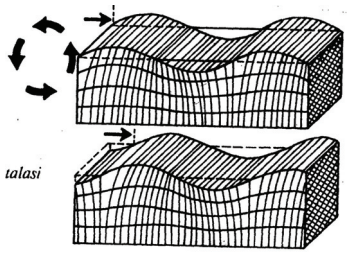


Figure 5:*Rayleigh waves*

The particles of the wave move through layers up and down with regard to the wave propagation.

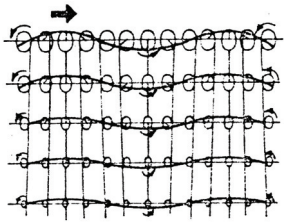


Figure 6: *Particle oscillation in Rayleigh waves*

The waves of either of these types have smaller propagation velocity than "P" and "S" waves, and Rayleigh waves have a smaller velocity than Love waves. Similar to sound waves as they are, seismic waves, either type "P" or "S" can reflect and refract (Donald's, Mohorovič's, Gutenberg's discontinuity). For that reason,in every earthquake, seismic field with a tangled mass of oscilations is created (figure 7).

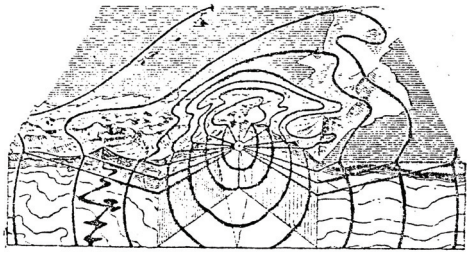


Figure 7: *Seismic wave propagation scheme*

That is why the records of an earthquake are often quite complex. If the propagation of a seismic wave is imagined to be direct, so called seismic wave, then, depending on the angle of eruption on the Earth's surface, its vertical and horizontal component will prevail. In the area in the immediate surroundings to the epicenter, its vertical component will prevail, but the further we get from the

epicenter, the greater the horizontal component is, which presents the greatest danger for the construction objects which are exposed to their vibration activity (figure 8).

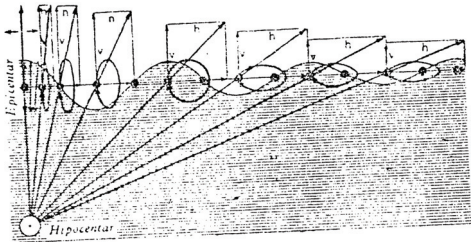


Figure 8: *the seismic wave components with regard to their position in relation to the position from the epicenter*

In every earthquake, three components of movement are determined: two horizontal and one vertical (figure 9). The larger the distance from the station to the epicenter, the weaker the intensity and clearness of the „P"waves are. To illustrate, aproximantely, at the distance of 1030 the records starts losing its clarity.

This obscurity is prolonged to the distance of 1420 after which it again becomes clear. The area in which the oscillations are not clearly presented is called „the obscure area of „P" waves" (figure 9).

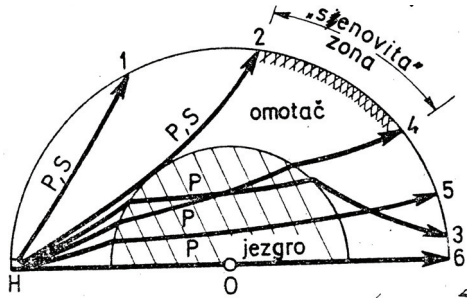


Figure 9. *„P" waves cutting through the boundary of mantel and nucleus, sharply refracting and thus creating „the obscure area"*

The relation between magnitude (M), amplitude (A) and an epicenter distance (E) are given in the form of empirical expressions. In order to determine the magnitude, in addition to amplitude, an epicenter distance, which is determined via the time difference between longitudinal and transverse waves, should be known. "P" wave travels first, while "S" waves comes later. The further the recorder is from the hearth of the earthquake, the greater the time interval between the arrival of one and the other waves (as already shown in the figure 3). If an earthquake is generated far from us, seismic waves will penetrate the depth of the Earth, because of which it will spread faster. In this sense, there are various tables made which give a quick answer to the problem of determining the hypocenter distance. It is possible to determine the source destination of an earthquake, i.e. the location of source of seismic energy, by observing seismographic records.However, seismic waves have other application too, e.g. In determining the Earth's structure to its center [2].

3. THE OSCILLATION EQUATIONS OF THE SEISMIC WAVES

Linear elastic, isotropic, homogeneous body with density ρ, where x_1, x_2 and x_3 appropriate movements; p_{ji}- a normal preasure and p_{ij} shearing preasure. On the basis of Dalambert's principle, the wave equation can be generated in the following form

$$p\frac{\partial^2 x_i}{\partial t^2} = \frac{\partial p_{ii}}{X_i} + \frac{\partial p_{ij}}{X_j} + \frac{\partial p_{ki}}{X_k} \tag{1}$$

if it is now

$$\theta = \frac{\partial x_i}{\partial X_i} + \frac{\partial x_j}{\partial X_j} + \frac{\partial x_k}{\partial X_k} \tag{2}$$

Cubic dilatation, the equition of movement expressed via displacement is

$$p\frac{\partial^2 x_i}{\partial t_2} = (\lambda + \mu)\frac{\partial \theta}{dX_i} + \mu\Delta^2 x_i \tag{3}$$

where Δ^2 is Laplace operator $\frac{\partial^2}{\partial X_1{}^2} + \frac{\partial^2}{\partial X_2{}^2} + \frac{\partial^2}{\partial X_3{}^2}$.

Attributing specific values to Lame's constants (4), we will get the special ideal materials. Thus, for $\mu = 0$ we get rigid body, $0<\mu<\infty$ the material is ideally deformable and for, a za $\mu = 0$ an ideal fluid.

$$\lambda = \frac{\nu E}{(1+\nu)(1-2\nu)} \qquad \mu = \frac{E}{2(1+\nu)}$$
$$E = \frac{\mu(3\lambda + 2\mu)}{\lambda + \mu} \qquad \nu = \frac{\lambda}{2(\lambda + \mu)} \tag{4}$$

where: E - Young module, ν - Poison koef., a μ=G je shearing module.

If we move rot operation to the equation (3), we get

$$p\frac{\partial^2}{\partial t^2} rot\, x_i = (\lambda + \mu) rot \frac{\partial \theta}{\partial X_i} + \mu\Delta^2 rot\, x_i \tag{5}$$

After certain transformations of the equation (5), we get the equation of simple waves, i.e.

$$p\frac{\partial^2}{\partial t^2} rot\, x_i = \mu\Delta^2 rot\, x_i \tag{6}$$

On the basis of which we can conclude that dilatation (or non/rotational) disturbance travels at speed:

$$\upsilon_p = \sqrt{\frac{\lambda + 2\mu}{p}} = \sqrt{\frac{(1-\nu)E}{(1-\nu-2\nu^2)p}} \tag{7}$$

Where the second form is induced from the first part of the equation (4). Similarly, the equation (6) shows that rotational disturbance (or one with the same volume) is transferred at the speed

$$\upsilon_s = \sqrt{\frac{\mu}{p}}, \text{ odnosno } \upsilon_p = \upsilon_s\sqrt{3} \text{ [5]} \tag{8}$$

We can see $\upsilon_p > \upsilon_s$. These two types of the waves are called, respectively, primary or P waves and secondary or S wave. In the points far enough from the source of disturbance, the waves can be treated as plane waves. Groups P and S which cut through the material respectively from space waves. However, in the surroundings of free and boundary areas of material with different properties, where Rayleigh, Love and other types of waves describe the movements [6]

If we accept that the Poison's relation λ=μ, for ν=1/4 and $\upsilon_p=\upsilon_s\sqrt{3}$ of a particular clay with the average water content

over 300% give the relations υ_p/υ_s whose size order is 15 (Figeueroa, 1964) which implies that ν=0.498.

As far as sphere waves in the small distance from the center of disturbance are concerned, the velocity and acceleration change with R^{-2}, while they decrease with R^{-1} (R is the distance from the center of the sphere).

Under the condition of cylindrical symmetry on the small distance from the source, θ approximately varies as long R. For greater distances from the center, corresponding asymptotic approximations are used, and for greater distances from the original disturbance, dilatation basically decreases as R-1/2 . The same can be applied to the movements in rotational waves. It is important to consider cylindrical waves with regard to surface earthquake waves at the great epicenter distances.

The ration between reflected and refracted waves and the direction of the incident waves is particularly simple, and the sinus of the angle which the direction of the expansion of the any wave (incident, reflected or refracted) makes with the normal axis on the border between the two elastic environments; it is proportional to the wave expansion velocity. To illustrate, according to the figure 9, if the Øp1 is the angle which the incident P wave forms with the normal axis on the border between Øp2 and Øp3, the appropriate angles for refracted and reflexive waves, and Øs2 and Øs3 for refracted and reflexive SV wave, respectively, then the ration of the angles can be illustrated with the expression

$$\phi_{p1} = \phi_{p3}$$

$$\frac{\sin\phi_{p1}}{\upsilon_{p1}} = \frac{\sin\phi_{p2}}{\upsilon_{p2}} = \frac{\sin\phi_{s2}}{\upsilon_{s2}} = \frac{\sin\phi_{s3}}{\upsilon_{s3}} \qquad (9)$$

The incident wave can trigger both P and SV waves, but not SH reflexive and refracted waves. For orthogonal and small angles, SV waves cannot be generated. For incident SV wave, reflected and refracted wave can be SV and but not SH.

Lets observe a homogeneous, isotropic, elastic mid-space which is bordered with two planes X1 and X2 above of which is vacuum. We are seeking a constant solution of the equation 3 which is usually limited to the surface and that the movements which lie on the axis OX2 are equal. Rayleigh has managed to find their solution. Therefore, υr fulfills the condition

$$(2-\frac{\upsilon_r^2}{\upsilon_s^2})^2 = 4(1-\frac{\upsilon_r^2}{\upsilon_p^2})^{1/2}(1-\frac{\upsilon_r^2}{\upsilon_s^2})^{1/2} \qquad (10)$$

For x2= 0. If Poison's ration is true, then the ratio (10) gives for υr = 0.92 υs and expressions for x1 and x3. For x3=0m for the duration time of the disturbance of the particles at the surface forms ellipse

$$x_1 = 0.42a\sin\beta \qquad x3 = -0.62a\cos\beta \qquad (11)$$

Where a is constant, and β a parameter which decreases with time. The ellipse is then circumscribed retrogardually. This type of movements is known as Rayleigh waves. The conclusion that xz=0 is contrasted to the observations. The earthquake surface waves usually represent a horizontal shearing component which spreads horizontally.

4. CONCLUSION

There are basically three types of seismic waves: longitudinal, longitudinal, primary or" P" waves, transverse, transverse, secondary or" S" and surface waves, Reyleigh" R" and" L" Love waves . Reyleigh waves have a vertical component, acting as a shock in the direction of moving in ellipses. Love waves are transverse and occur only in the horizontal plane and act like an earthquake. The forms of these waves vibrating particles are presented for a clearer understanding of the odgovarahućim images. In the right direction (longitudinal, lateral, vertical, horizontal, elliptical, etc.). Surface waves have a lower velocity of propagation of the" P" and" S" waves and relay less than Lavovih. Waves of type" P" and" S" type can also affect the pinch as shown in the pictures. Because instruments registered seismic waves have irregular vibratory movements both in direction and in amplitude, acceleration, periods, etc., as they pass through the different layers of the k-ka of which are rejected as well as cracks and interfaces between the layers, gathering primary and reflected waves and the like, and the tracks are very complex as shown in Fig.

With increasing distance from the station (which came first) to the epicenter, intensity and clarity" P" weak waves, a distance of about 103 ˚ to 142 ˚ record is not clear and is referred to as" shady" zona.Uzrok existence of zone consists in the fact that, roughly halfway from the center of the Earth, its texture is intenzivnomenja. area above this limit is called the mantle of the Earth, and the area beneath it - the core, as in the picture shown.

Spatial waves are formed by a group of" P" and" S" waves that cut the material independently of each other. If we adopt the Poisson ratio λ = μ3 for ν = 1/4 and υp = υs, certain clays with an average water content of over 300% are still related υp / υs the order of 15, which implies that νx = 0498. Laws governing reflection and refraction tlaasa can be derived from a consideration of continuity and balance and must be in accordance with the principles of geometric optics.

Seen a homogeneous, isotropic, elastic half-space is limited to the plane x1 and x2 above it by poretpostavci vacuum. for x3 = 0 (see the expressions x1 and x3, which are not listed here) during the existence of disturbances on the surface describes an ellipse; x1 = 0.42 • sinβ and x3 =-0.62 • cosβ, where β - parameter that decreases with time and this type of movement is known as Rayleigh waves are shown in Fig.

REFERENCES

[1] M. Milićević. S. Zdravković; Dinamika konstrukcija, Univerzitet u Nišu, 1984. Niš.

[2] B. Ćorić, S. Ranković, R. Salatić; Dinamika konstrukcija, Univerzitet u Beogradu, 1998, Beograd.

[3] S. Ivanović: Zemljotresi – fenomeni prirode, Titograd, 1991

[4] S. Ivanović: Inženjerska seizmologija (autorizovana predavanja), Titograd 1986

[5] D.Hadžijevski; Opšta seizmologija, IZIIS na Univerzitatas ''Kiril i metodij'' – Skopje, 1985.

[6] Newmark/Rosenbrueth; Osnovi zemljotresnog inženjerstva, IRO ''Građevinska knjiga'', Beograd, 1987

University of Nis
Faculty of Occupational Safety

„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

ADVANCED METHODS OF VIBRATION DIAGNOSTICS

Ranko Antunović[1]

[1] Univerzity of East Sarajevo, Faculty of Mechanical Engineering, BiH, Email: r.antunovic@teol.net

Abstract - *Vibrational Diagnostics Operational represents a multiple response measurement and analysis of measurement signals from the sensors from which to conclude the character of the dynamic behavior of the system which is based on establishing the cause of a malfunction, supervised the technical system. I have a diagnostic approach based on the fact that every dynamic disorder causes a certain movement or vibration of a true character. So far, developed and implemented a number of vibrational diagnostics methods with which we can unambiguously determine the existence of a true problem in machining operations.*

However it is possible to single out the methods of vibrational diagnostics with which to diagnose damage to the technical system in the phase of occurrence of this problem. In this way we can promptly detect the existence of defects, track propagation of damage and decrease the growth of the problem. This paper presents methods of vibrational diagnostics that are commonly used for early detection of defects in the work of rotating machinery.

1. INTRODUCTION

Occurrence of certain faults machine produces a fixed excitation power that produces a specific oscillatory movement. The analysis of vibration response with sensors system can determine the character of excitation force and determine the cause of machine malfunction.

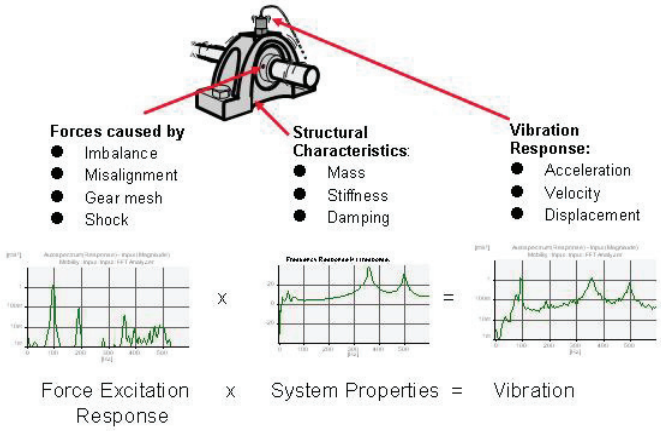


Fig. 1 *Dependence of vibration excitation force*

2. MONITORING SYSTEMS

In order to have available the necessary information for diagnostic assessment and analysis of technical systems there must be systems for the collection of all relevant data. With the existence of a system for collecting and analyzing relevant data, there must be an organizational management system machines that clearly defines who gets to see what information and who comes to the appropriate decision.

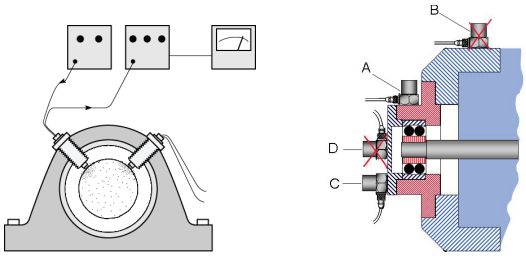


Fig. 2 *Eddy Current Proximity Probes and Choosing a Mounting Position*

Supervisory instrumentation is likely to signal analysis and conditioning, and communication with the computer and expert systems, other than the protection of performing diagnostic tests which reveal the cause of the defect and provide measures to eliminate it.

3. ADVANCED METHODS VIBRODIAGNOSTICS

Permanent monitoring of vibration can be easily designed if the monitored level of vibration (usually the level of vibration velocity) with an additional built-in relays that can signal exceeding a preset level of vibration. More complex than monitoring vibration monitoring vibration on the bearings and shaft, followed by phase angle of vibration with respect to the shaft and has additional capabilities of monitoring process parameters of the machine. However it is possible to extract methods vibrodiagnostic indicating the early onset of damage to the technical system. This will be shown some of vibrodiagnostics methods commonly used for early detection of defects and monitoring a particular problem in the work machine.

3.1. Orbital (dual) analysis

The orbit is mainly used for monitoring and analysis of rotor vibration in machines with plain bearings and it is a dynamic path of movement sleeve [1].

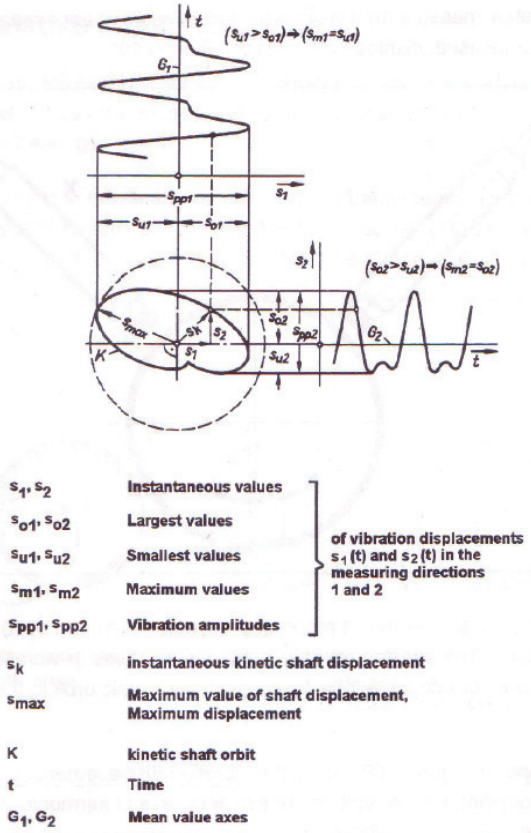


Fig. 3 *Preview formation orbit*

3.2. SED analysis

Selected envelope detection (SED) is a powerful analytical method that extracts and analyzes viskofrekventne modulated signals. It is used for damage detection of rolling bearings, gears, for monitoring cavitation, inductance motors, etc. [3].

The following figure shows the spectral envelop the view that in a simple way nedvosnislen indicates damage of rolling bearings [2].

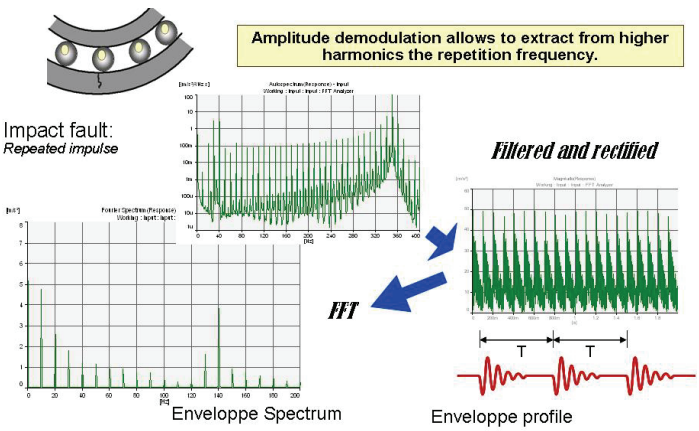


Fig.4 *Envelope Spectrum*

3.3. Cepstral analysis

By rotary machines are frequently present, the basic dynamic modulation phenomenon lead to the creation of harmonic frequency components around the main phenomena. This analysis is used to detect damage gears, beds, etc. [2].

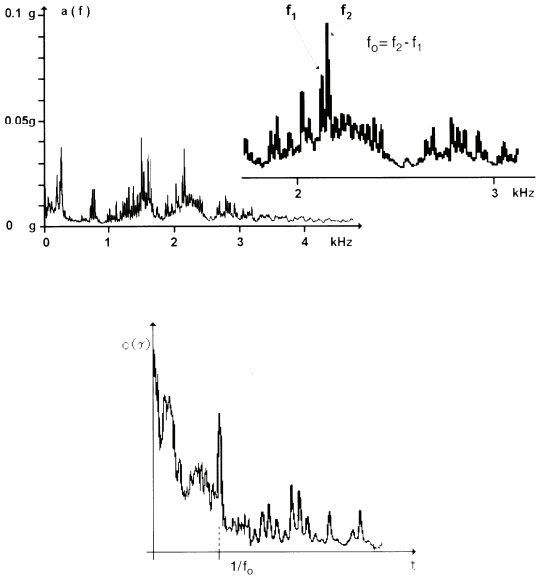


Fig. 5 *The manner of obtaining kepstra*

3.4. SEE Analysis

SEE SKF's method for detection of bearing failures and gears in the early stages of failure, as well as to detect cavitation, friction, cracks, electrical problems etc.. This method focuses on calculating the total energy spectrum for the high frequency range, typically frequencies between 150-500 kHz. It actually gives enveloping acoustic emission spectrum [4].

3.5. Modal analysis

In principle, modal analysis can be operationalized and classical modal analysis. Operational modal analysis is carried out in the paper machine. By carrying out this analysis we can determine the complex transfer function of the system caused by the forces in actual service [7].

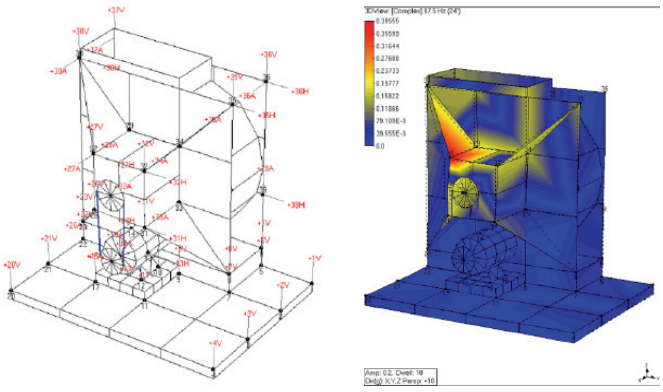


Fig. 6 *Virtual machine shifts obtained using operational modal analysis*

4. ANALYSIS OF RESULTS OF STUDY

This will be shown some of the results of diagnostic analysis of the practices using advanced methods previously mentioned vibracion diagnostics.

4.1. Analysis of the orbit and the elastic line of turbogenerator rotors

The analysis of the elastic line of turbo generators and appearance of individual bucket orbital view of vibration on the bearings is possible at an early stage to establish the existence of specific operational problems and diagnose its cause. Here is the analysis of line elastics turbogenerator rotor due to rotor crack propagation in it.

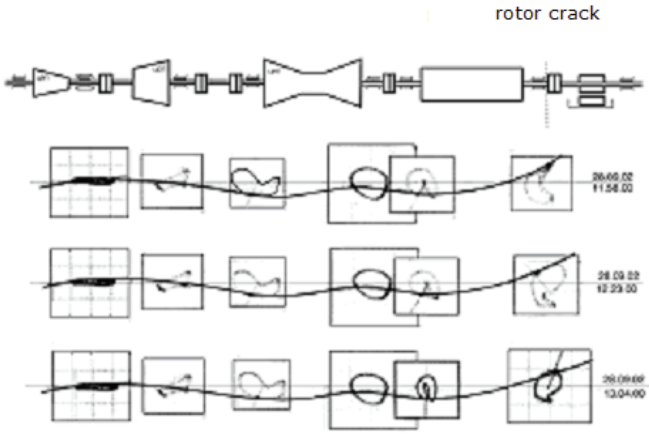


Fig. 7 *The appearance of elastic (modal) line associated with the orbits of the rotor during the propagation of cracks in the rotor*

4.2. Analysis of envelope

Here is a view that the spectral envelope in a simple way nedvosnislen indicates damage to the rolling bearing.

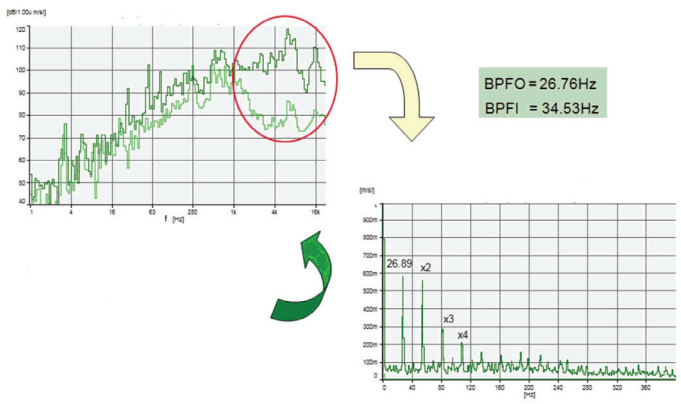


Fig. 8 *Comparative review of CPB and the spectrum envelope of the spectrum (center frequency 6 kHz frequency range and width of 6%), with damage to the outer track beds*

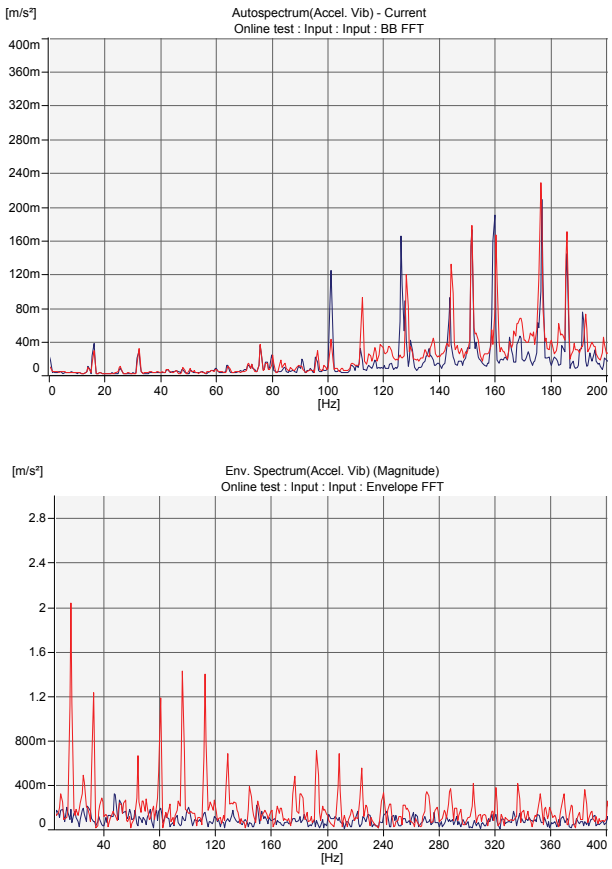


Fig. 9 *Comparative review of spectrum and spectrum envelope gear damage*

4.3. Cepstral analysis

Here is a look at the spectrum and kepstra damaged and undamaged gears.

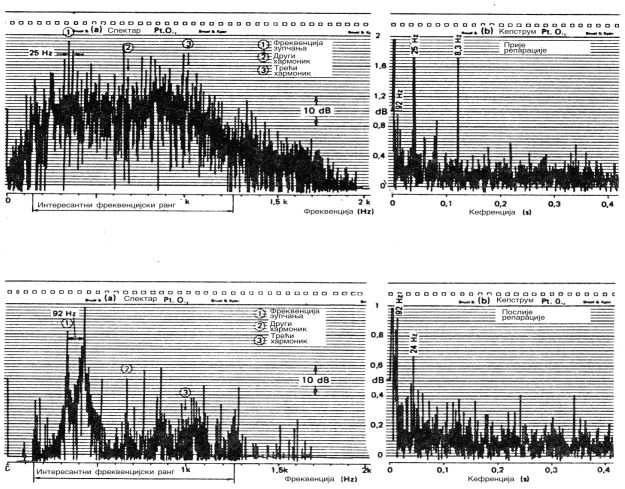


Fig. 10 *The appearance of the spectrum and kepstra gear before and after repair*

4.4. SEE analysis

Here is a comparative view of the spectrum envelope and the SEE spectrum of damage to rolling bearings.

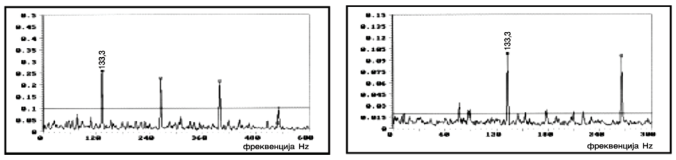


Fig. 11 *Display envelope acceleration and SEE spectrum of damage inside track roller bearing*

5. CONCLUSION

The progress of computer and measuring techniques, and continuous price reduction of development of computer hardware, allows today a significant step forward in monitoring and diagnosis of technical systems with financial investment is very acceptable. The application of modern systems of technical diagnostics, can be coupled with analytical methods, much better to explore the dynamic behavior of machines.

Using advanced methods of vibration diagnostics is possible to diagnose the damage to the machine in the phase of occurrence of a problem as time allows, we can detect problems in the work affect the prevention of further growth problems in some cases eliminated, and we give the problem. All this contributes to optimizing the performance of the machines in the production process and increasing the productivity of the manufacturing process as a whole.

REFERENCES

[1] Bently Nevada, *Predictive maintenance: How the pieces fit together*, Orbit, Vol.7, No.2, June 1986

[2] *Multi-channel & multi-task Analyzer-PULSE, Bruel & Kjaer advanced training course*, held in Budapest, Hungary, on 14-16 June 2005

[3] *Vibracion Diagnostic Guide*, SKF Reliability System, Application Note CM5003

[4] REVOLUTIONS, A Publication of SKF Condition Monitoring, Vol.7, Number 3

[5] *Enveloping Technology For Fast And Accurate Bearing Analzsis,* REVOLUTIONS, A Publication of SKF Condition Monitoring, Vol.3, Number 2

[6] Cepstrum Analysis, Bruel & Kjaer, Licture Note BA 7076

[7] Ward Heylen, Stefan Lammens, Paul Sas, *Modal Analysis Theory and Testing*, Kathoolieke Universiteit Leuven, 1997

[8] Agnes Muszynska, Ph.D., *VIBRACIONAL DIAGNOSTICS OF ROTATING MACHINERY MALFUNCTIONS***,** The Course in "Rotor Dynamics and Vibration in Turbomachinery", 21-25 Septembar 1992

[9] R.Antunovic, "Development of Sensor Oriented Dynamic Rotor Model as the Basis of Machine Diagnostics", Journal of Mechanics Engineering and Automation, ISSN 2159-5275 (online ISSN 2159-5283) by David Publishing Company located at 1840 Industrial Drive, Suite 160, Libertyville, Illinois 60048, USA, Vol.1, No.5,2011, pp. 351-356.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

VISCOELASTIC DAMPING ELEMENTS FOR VIBRATION REDUCTION

Marko Bek[1], *Nikola Holeček*[1], *Igor Emri*[2]

[1] Gorenje gospodinjski aparati, d.d., Partizanska 12, 3503 Velenje, Slovenia, marko.bek@gorenje.si
[2] Faculty of Mechanical Engineering, University of Ljubljana, Aškerčeva 6, 1000 Ljubljana, Slovenia

Abstract - *Transportation systems, including rail, are major polluters of the environment with noise and vibration, which is becoming an increasing ecological concern. The most important noise pollution source and most difficult to control especially in rail transport is so called rolling noise. Since polymers are known for their good absorptive capabilities, most of the existing damping elements use polymeric materials for damping vibration and noise. In scope of this work we investigate damping properties of polymeric materials for the purpose of vibration reduction.*

1. INTRODUCTION

Sustainable economic development is one of the main objectives of the European Union (EU), which requires economic growth without additional environmental influences. Any economic activity inevitably creates environmental impact. Reductions in the emission of greenhouse gases, which are responsible for global warming and associated to climate change, are a major concern of the EU. Around one quarter of all greenhouse gas emissions comes from transport activity [1, 2, 3] of which road transport takes the biggest share [4]. For this reason, the goal of EU transport policy is to minimize the current difference between road transport with 73% and railroad transport with 16% (for the inland freight transport) [5]. There are two major reasons for increasing share of rail transport, firstly, to decrease air pollution caused by exhaust gases and, secondly, to reduce noise pollution. Large portion of railway traffic in Europe is performed by electric trains [3] meaning that a shift from road to rail transport would have beneficial effect on the air quality, especially in urban areas. However, problem of noise nuisance for population living near rail lines as well as impact on wildlife [6] remains.

Noise is often defined as a source of undesirable form of sound. Regardless on the fact that more population is annoyed by road noise than by rail noise, increased volume of rail traffic (from expansion of rail networks and increased traffic on existing lines) could have negative impact on environment in the future. In 2002, Environmental Noise Directive was adopted and has led to establishment of noise maps of existing sources as well as to development of action plans to reduce noise in identified hot spots [7]. Many countries had also implemented limits of allowed noise levels at receiver locations. This leads to the conclusion that railway and infrastructure companies will have to consider minimizing noise on existing and in particular on new rail lines.

Minimizing noise levels can be achieved by implementing different noise control measures: increased vibration and noise damping, reduction of excitations, acoustic shielding and/or absorption and vibration insulation. In order for noise-control measures to be successful, the dominant source of noise should be identified. It has been determined that in many situations rolling noise is the dominant source of railway noise and is caused by wheel and rail vibrations induced at wheel/rail contact. Wheel and rail roughness generates relative vertical movements of them relative to each other. This generates vibrations which are transmitted into both structures and from structural noise radiated into the surrounding air [8]. In addition these movements significantly increase energy consumption.

Several reduction techniques for controlling rolling noise exist, among them are: grinding of rail surfaces, optimizing shape of rail wheels, replacing iron breaks with composite brakes, optimizing rail pads, sound barriers and tuned absorber systems. Currently soft rail pads are being used despite the fact that stiffer ones contribute to the reduction of energy consumption. Soft rail pads increase decay rate of rails and it is necessary to apply damping treatments since reducing decay rate is important. For this reason tuned absorber systems were introduced, where cost benefit analysis performed in STAIRRS project showed that for moderate costs tuned absorber systems give good results [9], leading to the conclusion that tuned absorber systems can be a very effective way in reducing the noise radiated by the rail.

Broader goal of this work is to reduce rail noise emission by utilizing tuned viscoelastic damping elements (TVDE) attached to the rail. TVDE's should be tuned to reduce vibrational amplitudes at frequencies which has the greatest contribution to the overall noise levels. For the best performance TVDE's should exhibit good damping properties in wide frequency and temperature range. Contact between rail and viscoelastic damping element should ensure maximal transfer of mechanical energy of the vibrating rail to the viscoelastic material.

Within the scope of this research it will be investigated how changes of the material inherent structure can affect the frequency range in which the material exhibits its maximum capability of mechanical energy absorption. Optimal damping effect is expected when the frequency of the material maximum damping properties matches the frequency of generated vibrations.

In order to investigate the expected effect we performed experiments with cantilever beam to which we attached

polymeric elements, made of thermoplastic polyurethane (TPU). Impulse acting on a cantilever beam causes vibrations of the beam in accordance to its dynamic properties, while polymeric elements attached to cantilever beam cause reduction of vibration amplitudes. To analyze the effect of material structure changes on its damping properties we manipulated material structure by changing the temperature of polymeric damping elements.

2. METHODOLOGY

To observe how changes of polymeric material inherent structure from which damping elements are made of affect their damping properties. To analyze this an experimental setup was designed and build. The experimental setup ensured the experimental conditions required to modify the material inherent structure which exhibits the required damping properties.

Observation of viscoelastic material damping properties was done by measuring response of a cantilever beam subjected to an impulse loading. Response was measured using accelerometer attached to the vibrating beam. Accelerometer used in this experiment was IMI 621B41 with measuring range from 2,4 Hz to 10 kHz, and sensitivity 10,2 mV/(m/s^2). Signal was conditioned using charge amplifier Omega AA-PS2, acquiring and digitalizing of data was done using NI USB – 6009 DAQ card. Real time signals were stored and used for off-line analysis. Using the Fourier transform we obtain the natural frequencies of the cantilever beam.

2.1 Cantilever beam

For the purpose of performed experiments we have chosen the cantilever beam with dimensions 500 × 50 × 3,44 mm, as shown in Figure 1. The accelerometer was placed 35,16 mm from the free edge of the cantilever beam. The beam with the effective length of 380 mm and weight of 645 g was then fixed to the concrete foundation, as shown in Fig. 2.

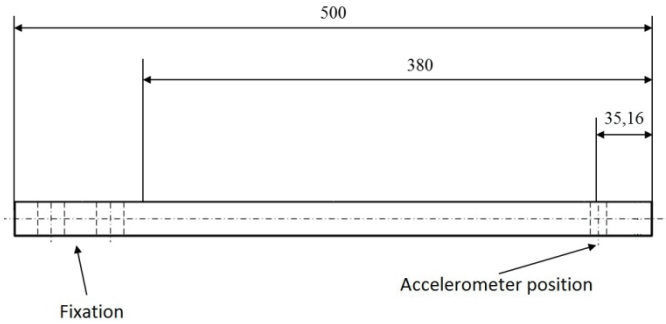


Fig. 1 *Dimensions of cantilever beam used for experiment*

2.2 Temperature chamber

In our experiments the inherent material structure and the corresponding damping properties were modified by its temperature therefore all experiments were conducted within an environmental chamber. For this purpose experimental setup, together with the loading mechanism, was placed into a temperature chamber showed in Figure 2. Chamber was thermally and acoustically insolated enabling that experiments were performed at constant conditions. Chamber was heated using heating-ventilation system that circulates air at set temperature into the chamber. Temperature range used during the experiments was 20 ÷ 70 °C, with the accuracy of ±3,2 °C.

Temperature monitoring was done using four thermocouples, three of which were placed on the cantilever beam and one on the ceiling inside the chamber.

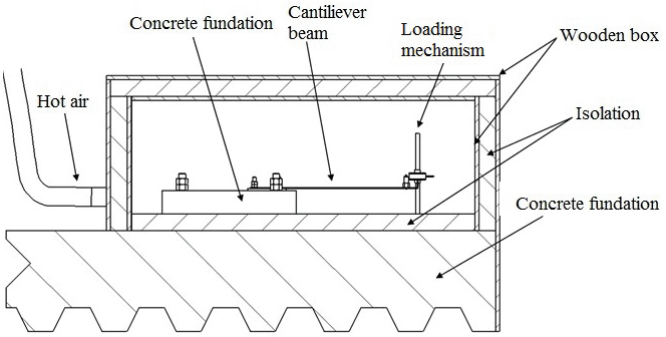


Fig. 2 *Temperature chamber*

2.3 Sample preparation

Samples were prepared from the thermoplastic polyurethane (TPU) supplied by BASF. Thermoplastic polyurethane is known for its good damping properties; however, it is important to point out that other polymeric materials are suitable for damping applications as well. TPU was just one of the materials we have investigated within our project. TPU material was obtained from the manufacturer in the form of granules of different sizes. Sample preparation procedure started with grinding of granules to smaller size, which prevented occurrence of air bubbles and other inhomogeneity in later steps of the procedure. For one sample with dimension 500×50 mm and thickness of 1 mm, 37 g of granulate material was needed. This material was then placed into a metal frame and a hydraulic press with heaters was used to melt and compress the material. Temperature used in this process was 125 °C. Granules were pressed for 10 min, followed with slow cooling to room temperature. Using this procedure we obtained 1 mm thick stripes of polymeric material.

In the experiment two damping elements were used (for both surfaces of the cantilever beam) to maximize damping abilities of the structure (Figure 3).

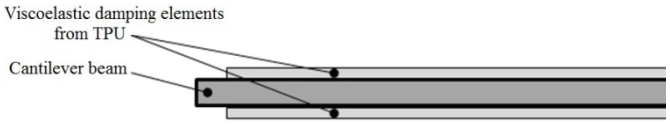


Fig. 3 *Cantilever beam with attached viscoelastic damping elements (VDE) made out of TPU*

After preparation of samples they were attached to the cantilever beam. Two-component epoxy adhesive Araldite 2011 was used for attaching samples to the both surfaces of the cantilever beam.

The entire surface of the cantilever beam was cleaned before applying the adhesive. Firstly, fine sandpaper was used to remove all impurities from the beam, secondly, acetone was used to degrease the surface of the beam. Next, very thin layer of the glue was applied to the beam, on top of which viscoelastic damping element was placed. The same procedure was used to place the second viscoelastic damping element. Cantilever beam with attached damping elements was then left to cure for 12 h.

2.5 Experimental procedure

Cantilever beam with attached viscoelastic damping elements (VDE) was placed into the heating chamber. Before starting the experiments the cantilever beam with VDE was heated to temperature 70 °C and kept at this conditions for 4 hours, and afterwords slowly cooled to the room temperature. With this annealing procedure we have eliminated all residual stresses and brought the material into the equilibrium state at selected boundary conditions. Experiments were conducted at temperatures 20°C, 30°C, 40°C, 50°C, 60°C, and 70°C. At each temperature six repetitions were made (Table 1).

Table 1 *Experimental procedure*

Cantilever beam with attached VDE	
Temperature	**No. repetitions**
20°C	6
30°C	6
40°C	6
50°C	6
60°C	6
70°C	6

When selected temperature of the cantilever beam was reached cantilever beam was deflected using special loading mechanism. Loading mechanism determines the initial deflection of cantilever beam. In presented experiments the beam was deflected for 8 mm ± 0,08 mm. Loading mechanism was triggered outside the temperature chamber, which assured stable temperature conditions inside the chamber. As it was mentioned in the previous section, signal was acquired, recorded and presented as an amplitude – frequency graphs.

3. RESULTS

Obtained results are presented in the form of amplitudes of vibrating beam in frequency domain. Figure 4 shows an example of the measured results for the cantilever beam with the attached viscoelastic damping elements at temperature 20°C. Two natural frequencies were observed, the first natural frequency at f_1=15,38 Hz, and the second at f_2=99,38 Hz.

To observe the effect of selected temperatures on the inherent material structure, and consequently on the damping properties of the viscoelastic elements, maximal amplitudes of the first and the second natural frequencies were measured, as shown in Fig. 4. Results presented in Figs. 5 and 6, show maximal vibrational amplitude as function of temperature at which experiments were conducted. Figure 5 shows results for the first natural frequency, whereas Figure 6 shows results for the second natural frequency.

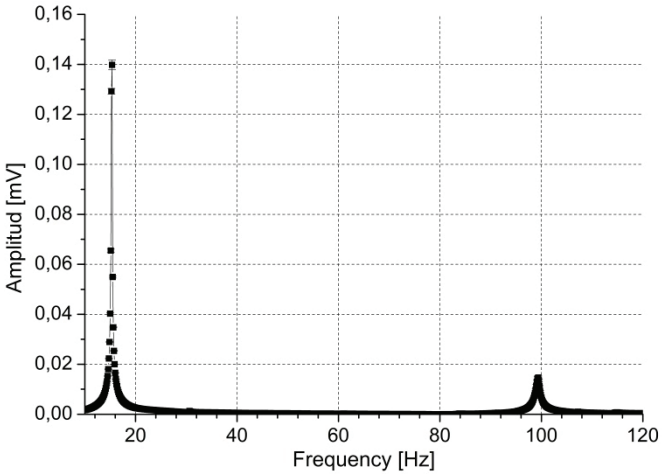


Fig. 4 *Example of measured result for cantilever beam with attached viscoelastic damping elements at temperature 20 °C*

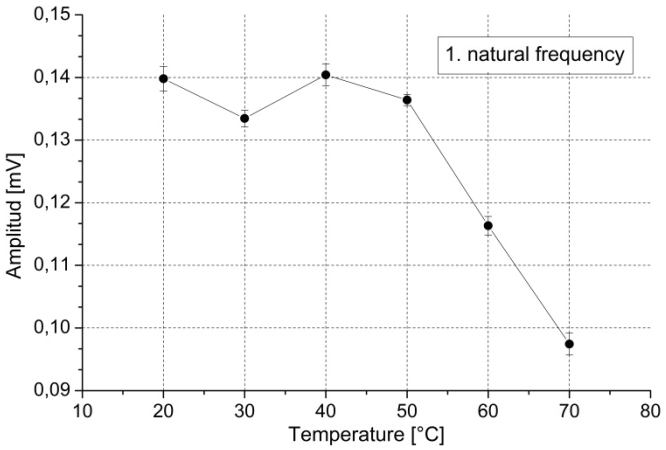


Fig. 5 *Maximal amplitude of first natural frequency in dependence on temperature*

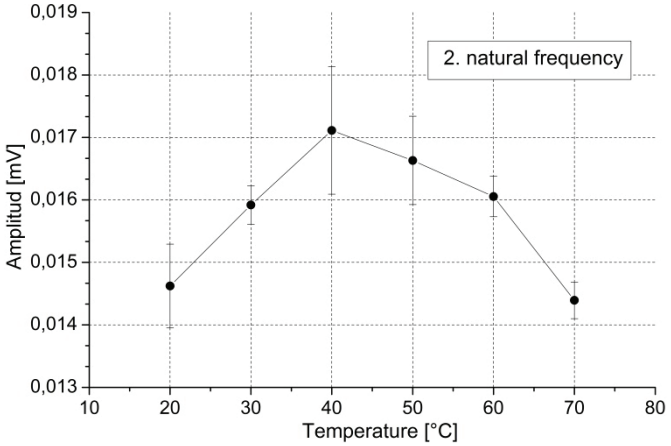


Fig. 6 *Maximal amplitude of second natural frequency in dependence on temperature*

From the presented results we can observe a general trend that maximal amplitudes occur at temperature around 40 °C. In case of the first natural frequency there is a drop of maximal amplitudes after 50°C. Simmilarly, we can observe drop of amplitudes after 50°C in the case of the second natural frequency. In addition we observe lower amplitudes for the second natural frequency at temperatures 20°C and 30°C.

Results clearly show maximal amplitudes at temperatures around 40 °C, which indicates that selected viscoelastic material has the worst damping properties at this conditions. As expected, it can be seen also that properties of viscoelastic damping elements change with temperature. In the case of first natural frequency the maximal difference between amplitudes is around 47 %, in the case of the second natural frequency this difference is around 17 % only.

4. CONCLUSIONS

It may be expected that role of rail transport will increase significantly in coming years. One of the problems facing rail transport is noise and vibration which is generated during working conditions of trains. The most important noise pollution source and most difficult to control is rolling noise.

Several reduction techniques for controlling rolling noise exist. Currently soft rail pads are being used together with tuned absorber systems. Most of existing solutions implement polymers as materials used for damping of unwanted vibration and noise.

Within the scope of this research it was investigated how changes of inherent polymeric material structure can affect the frequency range in which the material exhibits its maximum capability of mechanical energy absorption. Optimal damping was expected within some frequency range.

In order to investigate this effect we performed experiments on cantilever beam to which viscoelastic polymeric elements, made of thermoplastic polyurethane (TPU) were attached. Excitation of a cantilever beam was done using impulse excitation, free vibrations were measured using an accelerometer attached to the end of the cantilever beam.

Results showed that temperature has an important effect on damping properties of viscoelastic damping material. In case of the first natural frequency the maximal difference between the amplitudes was found to be around 47 % and in the case of the second natural frequency this difference was found to be around 17 %. Results showed that at certain temperature there is a range of frequencies at which damping properties are very poor. For both, the first nad the second natural frequency this occurres at about 40°C.

It is important to stress that presented results are preliminary. For deeper understandment of the behavior of polymeric damping characteristics further research is needed, e.g.:

- Exact characterization of damping material using controlled stress rheometer;
- Select TPUs that have a maximum or close to maximum in tan δ at service temperatures for rails (from -50 ° to 50 °C);
- Make layered structures (out of different polymeric materials) to maximize damping ability of elements.

REFERENCES

[1] EC-JRC/PBL. EDGAR version 4.2. [Online] 2011. [Cited: May 12, 2012.] http://edgar.jrc.ec.europa.eu/.

[2] International Transport Forum, OECD. Transport Outlook. [Online] May 2010. [Cited: May 10, 2012.] http://www.internationaltransportforum.org/Pub/pdf/10GHGTrends.pdf.

[3] Railways, International Union of. Rail Transport and Environment, FACTS & FIGURES. [Online] 2008. [Cited: January 10, 2012.] http://www.uic.org/homepage/railways&environment_facts&figures.pdf.

[4] European Commission Mobility and transport. [Online] 2011. [Cited: February 22, 2012.] http://ec.europa.eu/transport/publications/statistics/doc/2011/pocketbook2011.pdf. ISBN 978-92-79-19508-2.

[5] Road Freight Transport Vademecum 2010 Report. [Online] September 2011. [Cited: 20 December 2011.] http://ec.europa.eu/transport/road/doc/2010-road-freight-vademecum.pdf.

[6] Habitat fragmentation due to transportation infrastructure, The european review. [Online] 2002. [Cited: 12 January 2011.] https://www.milieuinfo.be/productie/beheerplone/nietacm/iene/cost-341/SotA-COST341ER0318.pdf.

[7] Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. s.l. : Official Journal of the European Communities, 2002, pp. L189/12-25.

[8] Thompson, David. Railway noise and vibration: mechanisms, modelling and means of control. Oxford : Elsevier, 2009. ISBN-13: 978-0-08-045147-3.

[9] Strategies and Tools to Assess and Implement noise - final technical report. Transport Research Knowledge Centre. [Online] 2003. [Cited: 15 January 2012.] http://www.transport-research.info/Upload/Documents/201003/20100310_134523_78957_Final%20Report%20V10_2_.pdf.

University of Nis
Faculty of Occupational Safety

„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

DYNAMIC LOAD TESTING OF BRIDGES

Valentina Golubović-Bugarski[1], *Aleksandar Borković*[2]

[1] University of Banja Luka, Faculty of Mechanical Engineering, Bosnia and Herzegovina, valentina.gb@unibl.rs
[2] University of Banja Luka, Faculty of Architecture and Civil Engineering, Bosnia and Herzegovina

Abstract - *This paper deals with the experimental dynamic analysis of civil engineering structures, with an emphasis on dynamic testing of bridges. Dynamic behavior of the structure is described by modal parameters (resonant frequencies, damping, modal shapes) that can be identified using modal testing. Basic principles of two approaches in modal testing, experimantal modal analysis (input-output modal testing) and operational modal analysis (output-only modal testing) are shown in the first part of paper. Dynamic load testing of bridges as an important part of the acceptance process for new bridges is shown in addition. The relevant technical regulations in the field of testing of bridge structures is commented. Practical experiences in the use of output-only modal testing technique for dynamic load testing of bridges are illustrated from measurement examples done on two bridges in Banja Luka.*

1. INTRODUCTION

Structural analysis is the engineering discipline concerned with the behavior of structures subjected to static and dynamic load. When it comes to the static load of the structure, behavior of structures can be accurately predict by using numerical methods. However, for dynamic load there are certain parameters that are difficult to be modeled, e.g. damping of the structure. Therefore, it is necessary to conduct some experimental tests in order to better determine the dynamic behavior of structures. Two decades ago, the main interest of the engineering community has been focused on the development and application of new and powerful numerical methods for static and dynamic testing of structures. The rapid development of analysis techniques based on finite-element method has enabled engineers to use software package for accurate simulation of structural behavior.

However, the design and construction of more and more complex and ambitious structures, especially in the field of civil engineering (dams, suspension and cable-stayed bridges, towers, stadiums and other special structures), imposed the necessity of developing new experimental tools that allow accurate determination of the relevant static and dynamic characteristics. These experimental tools should provide reliable data to suport the calibrating, validating and updating of numerical FE model of the structure developed in the design stage, as well as for troubleshooting, benchmarking, quality control or structural health monitoring.

2. EMA and OMA IN STRUCTURAL DYNAMICS TESTING

Dynamic behavior of the structure is described by modal parameters (resonant frequencies, damping, modal shapes) that can be identified using modal testing. Generally, there are two basic approaches to modal testing:

- Input-output Modal Testing (Experimental Modal Analysis, Forsed Vibration Testing);
- Output-only Modal Testing (Operational Modal Analysis, Ambient or Natural-Excitation Modal Analysis).

Besides this classification, it is possible to classify modal testing in terms of the load that excites the structure:

- Forced vibration testing (a structure is excited in artificial way, using a shaker or impulse hammer);
- Ambient vibration testing (a structure is excited by ambient forces like wind, waves, traffic);
- Free vibration testing, (a structure is excited by suddenly dropping a load on a structure).

2.1. Experimental modal analysis (EMA)

Experimental modal analysis is a conventional modal testing based on the determination of a set of frequency response functions (FRFs) as the relation between induced force and the corresponding responses of structure taken at several positions at the structure, with the spatial and frequency resolution high enough to allow the identification of all relevant modes. Measuring chain that is used to determine the FRFs consists of a mechanism of excitation, response mechanism and a mechanism for the acquisition, storage and processing of data, where simultaneous measurement of excitation and structure responses is essential, [1].

In small and medium-size structures, the excitation can be induced by an impulse hammer. The advantage of this type of excitation is a wide-band input that is able to stimulate different modes of vibration. The main drawbacks are the relatively low frequency resolution of the spectral estimates and the lack of energy to excite some relevant modes of vibration. An alternative is the use of large electrodynamic shakers, which can apply a large variety of input signals (random, multi-sine, etc.) when duly controlled both in frequency and amplitude using a signal generator and a power amplifier. The shakers have the capacity to excite structures in a lower frequency range and higher frequency

resolution. The main drawbeck of the controlled excitation of large civil engineering structures is use of heavy excitation equipment which are only available at well equipped laboratories.

Dynamic response of a structure is usually measured by accelerometers-piezoelectric, piezoresistive, capacitive or force balance. Basic characteristics of piezoelectric accelerometers are that don′t require power supply and operate well in a wide frequency range, but most of them are not suitable for low-frequency measurements. Other types of accelerometers have a good cability in the low-frequency range, but require signal amplification.

Data acquisition and processing is performed using the A / D converter in the measurement chain. Raw data, acceleration time history can be multiplied by appropriate time window (Hanning) to minimize leakage effect and subdivided into different blocks to calculate autospectrum and cross-spectrum using FFT analyzer. Finally, FRFs can be obtained using H1 or H2 estimators. Further analysis of FRFs requires special software to analysis and process the signals.

EMA has obtained substantial progress in the last three decades. Numerous modal identification algorithms, from Single-Input/Single-Output (SISO), Single-Input/Multi-Output (SIMO) to Multi-Input/Multi-Output (MIMO) techniques in Time Domain (TD), Frequency Domain (FD) and Spatial Domain (SD), have been developed.

However, traditional EMA has some limitations, such as, [2]:

- In traditional EMA, artificial excitation is normally conducted in order to measure Frequency Response Functions (FRFs) or corresponding Impulse Response Functions (IRFs). FRF or IRF would be very difficult or even impossible to be measured in the field test and/or for large structures;
- Traditional EMA is normally conducted in the lab environment. However, in many industrial applications, the real operation condition may differ significantly from those applied in the lab testing;
- Component, instead of complete system, is often tested in the lab environment, and boundary condition should be reasonably simulated.

2.2. Operational modal analysis (OMA)

Since early 1990's, operational modal analysis has drawn great attention in civil engineering community with applications for off-shore platforms, buildings, towers, bridges, etc. A main difference compared to the traditional modal analysis technique is that measurement of the input forces is not required.

This enables testing of structures under operating conditions or in other situations were the input forces are impossible to measure. It is therefore also called Ambient Modal, Natural-Excitation or Output- Only Modal Analysis. It is now being applied to mechanical and aerospace engineering applications (rotating machinery, on-road testing, in-flight testing).

The advantage of this technique is that a modal model can be generated while the structure is under operating conditions. That is, a model within thrue boundary conditions and actual force and vibration levels. Performing modal test under operating (ambient or natural) conditions, like wind, waves or traffic, means that the structure is subjected to realistic vibration behaviour, which might be difficult to obtain by use of artificial excitation in traditional modal testing. Another advantage of the technique is the ability to perform modal testing in-situ, i.e. without removing parts under test. The test can be performed with other applications or activities in parallel and does not affect or interrupt daily use of the investigated structure. The measured responses are governed by the dynamic characteristics of the system and the ambinet forces, which excite the system. The derived model thus contains information of both the system characteristics as well as the excitation signals. This is one of the challenges in Operation Modal Analysis and some understanding of the nature and the characteristics of the excitation forces are therefore very important in order to interpret and understand the results and be able to derive a proper modal model, [3].

3. OUTPUT - ONLY (OMA) MODAL PARAMETER IDENTIFICATION

There are two main groups of output-only modal identification methods – nonparametric methods essentially developed in the frequency domain and parametric methods in the time domain.

The basic frequency domain OMA method is Peak Picking method (PP). This is the simplest known method for identifying the modal parameters of civil engineering structures subjected to ambient vibration loading. The method is initially based on the fact that the FRF goes through extreme values around the natural frequencies. The frequency at which this extreme value occurs is a good estimate for the frequency of the system. In the context of ambient vibration measurements the FRF is only replaced by the auto spectra of the ambient outputs. In such a way the natural frequencies are simply determined from the observation of the peaks on the graphs of the averaged normalized power spectral densities (ANPSDs). The ANPSDs are basically obtained by converting the measured accelerations to the frequency domain by a discrete Fourier transform (DFT), [4].

Although the input forces are not measured in ambient vibration testing, this problem has often been circumvented by adopting a derived modal parameter identification technique where the reference sensor signal is used as an "input" and the FRFs and coherence functions are computed for each measurement point with respect to this reference sensor. It not only helps in the identification of the resonances, but also yields the operational shapes that are not the mode shapes, but almost always correspond to them. The coherence function computed for two simultaneously recorded output signals has values close to one at the resonance frequencies because of the high signal-to-noise ratio at these frequencies. Consequently inspecting the coherence function may assist to select the frequencies.

In current peak picking method, the components of the mode shapes are determined by the values of the transfer functions at the natural frequencies. Note that in the context of ambient testing, transfer function does not mean the ratio of response over input force, but rather the ratio of response measured by a roving sensor over response measured by a reference sensor. So every transfer function yields a mode shape

component relative to the reference sensor. Here it is assumed that the dynamic response at resonance is only dominated by one mode. The validity of this assumption increases as the modes are better separated and as the damping in the structure is lower. The peak picking is a kind of frequency domain based technique. Frequency domain algorithms are most popular, mainly due to their simplicity and processing speed, and also for historical reasons.

The Peak Picking technique gives reasonable modal estimates if the modes are well separated. The main advantages compared to the time domain techniques are that it has no bother with computational modes and is much faster and simpler to use. However, for a complex structure, PSD peak picking technique is inaccurate. The accuracy of modal frequency estimation is limited to the frequency resolution of the PSD spectrum, operational deflection shapes is obtained instead of real mode shapes, damping ratio estimation via half-power point is inaccurate or impossible. Moreover, PP technique is hardly applied for the structure with closely spaced modes, which is often encountered when dealing with real world complex structures, [2].

In spite of these drawbacks many civil engineering cases exist where the peak-picking technique is successfully applied. The popularity of the method is due to its implementation simplicity and its speed.

The frequency domain approach was subsequently improved by performing a single-value decomposition (SVD) of the matrix of response (outputs) spectra to obtain power spectral densities of a set of SDOF systems. This new frquency domaina technique named as frequency domain decomposition (FDD), was implemented in 2000 [5], and the first generation of FDD can only estimate modal frequencies and mode shapes. The second generation of FDD, which is called as Enhanced frequency domain decomposition (EFDD) has been followed for estimation of not only modal frequencies and mode shapes, but damping ratios. In this last approach (EFDD), these estimates are obtained through inspection of the decay of auto-correlation functions evaluated by performing the inverse Fourier transform of the SDOF systems' power spectral densities, [6]. The third generation of FDD, i.e. Frequency-Spatial Domain Decomposition (FSDD), has been developed recently.

4. TESTING OF BRIDGES WITH THE TEST LOAD

Load testing of bridges is an important part of the acceptance process for new bridges. In our country, it is normalized by JUS U.M1.046 norm and according to it all bridges of span greater than 15 m are required to be tested, [7]. This standard determines the type of load, investigation procedures and assessment of test results. The objective of load testing is to determine the behavior of the bridge under static and dynamic loading in respect to:

- compliance with project;
- compliance of quality of the work in relation to required in project;
- capability of the bridge to takes over anticipated loads;
- durability of structure that is in use.

A bridge is technically correct if the following requirements are met:

- measured deflections and displacements are smaller or equal to the theoretical;
- permanent deflections measured after unloading are less than the prescribed percentage of the maximum measured deflection at this position;
- the measured crack width is less than the allowed value;
- the dynamic behavior under the dynamic load test is satisfactory.

The purpose of the dynamic load test is to determine the controlling parameters of the dynamic behavior of the bridges. The main dynamic characteristics of the structure are the fundamental vibration frequency, the dynamic amplification factor and the logarithmic decrement. These properties are usually not analyzed in detail in the design phase of small and middle sized structures. Some parameters, such as the logarithmic decrement or the dynamic amplification factor, can only be roughly estimated at the time of the design. However, these quantities are relatively easy to obtain experimentally, and can give valuable information for the exploitation and maintenance of the bridge. For dynamic testing of bridges following measurements are required:

- measuring the vertical deflection in the middle of the selected span while load crossing over bridge;
- measuring the speed at which the load crosses over bridge;
- measuring the others dynamic characteristic (resonant frequencies or periods of vibration), if program of testing requires.

Dynamic behavior of bridge is satisfactory if:

- vibrations do not create a feeling of discomfort for the user (tremor occurrence, resonance, the displacement amplitude and frequency that causes a feeling of embarrassment, etc.);
- the dynamic amplification factor is determined from the results of tests varies within the limits defined by the project ($\varphi_{d,measured} \approx \varphi_{d,\ calculated}$);
- measured periods of free oscillations are within the theoretical value ($T_{measured} \approx T_{calculated}$).

Methodology of dynamic load testing of bridges is in accordance with Output-only modal analysis method (OMA) previously presented. Dynamic load testing is performed by exciting the vibration of the bridge and by measuring its vibration responses due to this excitation. Several methods are available for the excitation of the bridge, in particular: eccentric rotating masses, impact of a heavy weight and by passing of a loaded truck. This last method is often preferred for the dynamic load testing of bridges because it gives, along with reasonably accurate values of the above mentioned quantities, a good approximation of the effect of the actual traffic on the structure. By varying the speed of the truck on the bridge, the full range of traffic speeds can be investigated, [8]. Furthermore, this method is easily implemented while some of the other ones necessitate more

complicated installation procedures. The measurements are taken and recorded by a dynamic data acquisition system with integrated Fast-Fourier Transform (FFT) analyzer, allowing an immediate interpretation of the results during the test. The effect of a deterioration of the pavement is simulated by the introduction of a plank on the path of the truck. This induces a strong impact when the truck passes at mid-span, that represents the effect of a hole in the pavement, or the irregularity of the surface caused by packed snow.

In addition, two case studies of dynamic testing of bridges with test load are shown, [9, 10].

4.2. Case study 1: Bridge over river Vrbas in Banja Luka

The new bridge "Incel" over river Vrbas was built in 2009. The bridge structure is a composite structure consisting of a steel space truss coupled with reinforced concrete deck and a steel orthotropic plate at the bottom flange in the zone of column S2. The bridge is continuous girder over two spans, 52.5 m and 36.75 m, total length of 89.25 m, Figure 1.

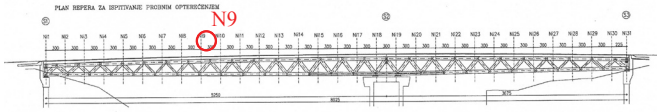


Fig.1 *Plan of benchmarks on the bridge structure*

According to the program of dynamic testing, the load of the bridge was performed in two phases:

1. Two trucks cross over bridge at speed of 40 km/h (minimum gross-mass of one truck: 32 t);
2. Two trucks cross over bridge at speed of 40 km/h; an obstacle is introduced at the path of trucks (two planks of 5 cm height, set at the middle of the first bridge span), Figure 2.

Responses of the structure were measured in vertical direction with accelerometers set in two positions, Fig.1:

- N9 (0.4L1) - reference signal "response 1";
- N8 – signal "response 2".



Fig. 2 T*wo trucks cross over planks*

Signals were captured by multichannel analyzer PULSE 3560C, Bruel&Kjaer, Figur 3. Accelerometers were attached to the pedestrian path by cement. The goal of investigation was to determine the natural frequencies of construction and verify the numerical FE model of the bridge, as well as to determine the dynamic amplification factor as ratio between the maximum vertical dynamic deflection in the middle of the selected span (determined while load crossing over bridge) and maximum vertical static deflection (determined in the static load test). To determine natural frequencies of the bridge, the cross-spectrum function was measured through auto-spectrum functions of two response signals, in the frequency span of 0-20 Hz. Other measuring parameters were: 0.2 Hz frequency resolution; 5 s time window; 20 exponental averaging, "Hanning" window function for response signals. Time and auto-spectrum function (power spectral density) were measured for each signal, as well as cross-specturm function between these two signals. Measuring data (for each measured function) were stored in so called "multibuffers" during measurement period of 50 s, Figure 4. Three consecutive measurements were performed, with same parameters of excitation and response.

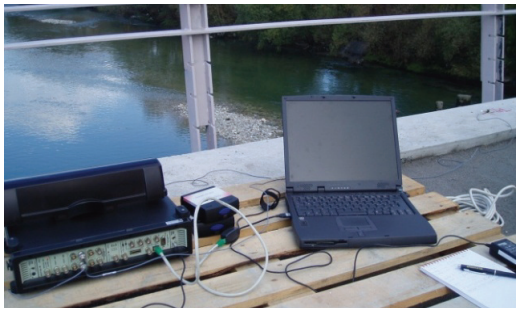


Fig. 3 *Measurement equipment*

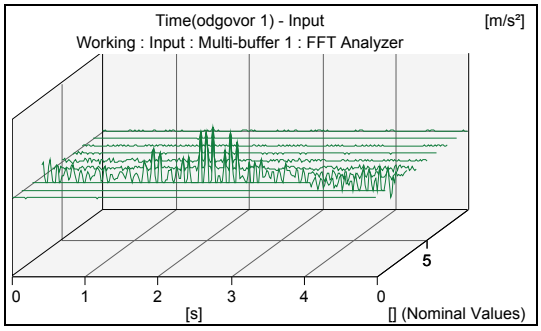


Fig. 4 *Time data stored in multibuffer*

Autospectrum functions of measured responses 1 and 2 and cross-spectrum from the first phase of testing (trucks cross over bridge with speed 40 km/h) are shown in Figure 5. The maximum measured vertical acceleration induced at mid-span of the bridge due to induced excitation was 1.6 m/s^2.

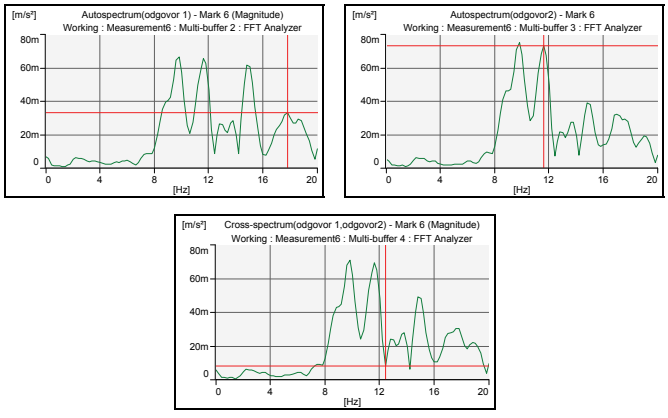


Fig. 5. *Autospectrums and Cross-spectrum from the first testing of bridge*

Autospectrum functions of measured responses 1 and 2 and cross-spectrum for the second phase of testing (trucks cross over planks at speed 40 km/h) are shown in Figure 6.

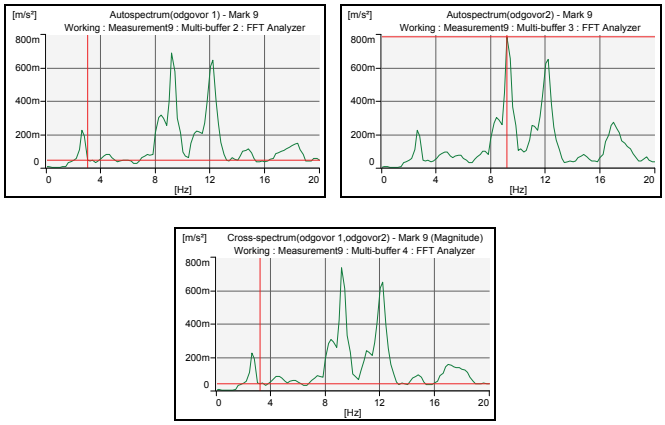


Fig. 6 *Autospectrums and Cross-spectrum function from the second testing of bridge*

In the cross-specturm function there are a few dominated peaks at frequencies: 2.6 Hz, 9.2 Hz, 12.2 Hz, 17 Hz. Modes of vibration with corresponding natural frequencies that are determined by numerical FE analysis determines are shown in Table 1. It can be noted that dynamic testing resulted with well excited the second and the third mode of structure, that corresponding well with the numerically estimated modes.

Table 1 *Numerically determined modes of vibration*

Out.Case	StepType	StepNum	Period	Freq.
Text	Text	Unitless	Sec	Cyc/sec
MODAL	Mode	1	0.195185	5.1233
MODAL	Mode	2	0.103976	9.6176
MODAL	Mode	3	0.082828	12.073
MODAL	Mode	4	0.0763	13.106
MODAL	Mode	5	0.058195	17.184
MODAL	Mode	6	0.048041	20.816

4.2. Case study 2: Pedestrian bridge in Banja Luka

When it comes to pedestrian bridges, in the most cases the vibration problems of a pedestrian bridges are caused by pedestrians stepping across the bridge. The usual frequency of human steps is about 2 Hz. Showing the higher probability, 95% of pedestrians walk in tact between 1.65 Hz and 2.35 Hz. However, as the length of the bridge is limited (and thus a period of excitation), even a bridge that has its natural frequency into these limits will not usually be brought into the state of infinite amplitude (resonance which would lead to the collapse of the structure). Pedestrian bridges should have its natural frequencies outside the range of 0.8 Hz to 5.5 Hz. This requirement is derived from the experience of many pedestrian bridges, where it was observed that the bridges having frequencies in this range is very unpleasant to use. Since the natural frequencies depend on the span of the bridge, which is pre-determined (crossing over the river, roads, intersections, inlets, etc.), it is very difficult to avoid that some natural frequency is not within this range. These problems of usability, expressed as discomfort by users of the bridge, are mostly psychological in nature (discomfort of "swinging" bridge), and rarely can become real load problems. To describe the human feeling caused by vibration of the pedestrian bridge, indicative values are presented in Table 2, which are related to the human who doesn't move, and is subjected to vertical harmonic vibration, [11].

Table 2 *Description of vibration of a footbridge*

Description of vibration for users of a footbridge	Frequency span 1 ÷ 10 Hz	Frequency span 10 ÷ 100 Hz
	Max. accel. (mm/sek^2)	Max. velocity (mm/sek)
barely noticeable vib.	34	0.5
clearly noticeable vib.	100	1.3
unpleasant vibrations	550	6.8
unbearable vibration	1.800	13.8

As an example of dynamic testing of pedestrian bridges, vibration testing of the newly constructed pedestrian bridge at Boulevard of Desanka Maksimovic in Banja Luka is shown, Figure 7.



Fig. 7 *Pedestrian bridge in Banja Luka*

According to the program of dynamic testing, the load is carried by a small vibratory drum roller, weighing about 1500 kg and moving at speed of 0.5 m/s along the pedestrian path, Figure 8. Acceleration was measured as a response of the structure, simultaneously by two accelerometers (type 4507, Bruel&Kjaer) placed on two positions:

- Response 1: at the middle of the pedestrian span;
- Response 2: at the distance of 1m from response 1.



Fig. 8 *Excitation induced by small vibratory drum roller*

Signals were captured by multichannel analyzer PULSE 3560C, B&K. Accelerometers were attached to the pedestrian path by cement. The aim of dynamic testing was to determine the dynamic behavior of pedestrian bridge under the real operation and whether there is an increased vibration responses in the frequency span of 1 Hz to 5 Hz. It was

decided to measure the frequency reponse of the structure in the frequency span of 0÷10 Hz by measuring the time functions and autospectrum functions for each respone signal, as well as the cross-spectrum function between these signals. Three consecutive measurements were performed, with same parameters of excitation and response. At the beginning of measurement, the vibration response of the structures was corresponded to the excitation (roller) position at the junction of concrete stairs with steel bridge construction. The measured cross-spectrum response function, Figure 9, showed the first natural frequency at 5.2 Hz. During movement of the excitation (roller) along the pedestrian path, cross-spectrum response functions showed a change of natural frequency to 4.8 Hz, which is the inevitable consequence of the influence of additional mass moving load, Figure 10. The measured maximum amplitude of acceleration was 348 mm/s^2, Figure 11, so this pedestrian bridge belongs to category of structures with clearly perceptible vibrations.

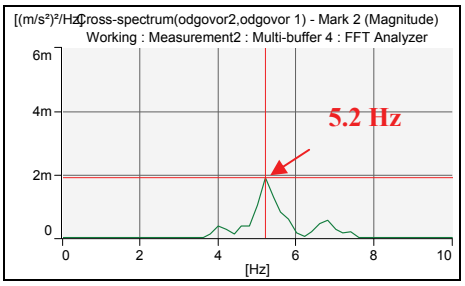


Fig. 9 *Cross-spectrum function at the beginning of measurement, resonant frequency at 5.2 Hz*

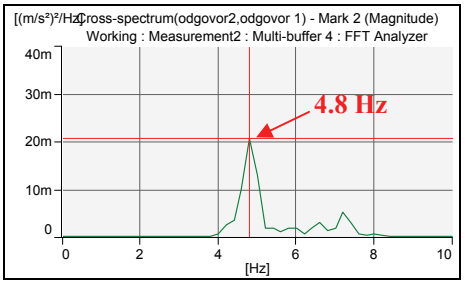


Fig. 10 *Cross-spectrum function for excitation at the middle span of pedestrian bridge, resonant frequency at 4.8 Hz*

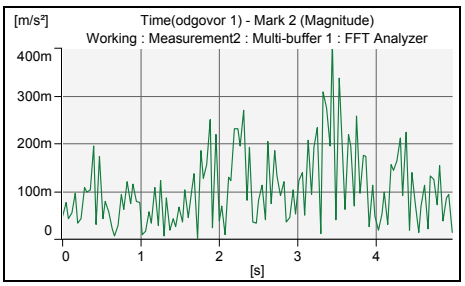


Fig. 11 *Part of Time function for excitation at the middle span of pedestrian bridge*

5. CONCLUSION

Bridges, as a representative of civil engineering structures, have particular characteristics (large size and relatively low natural frequencies) that make the current application of classical input-output modal identification techniques difficult. Therefore, there is presently a clear tendency worldwide to explore and improve the potential of output-only modal identification techniques. The advantage of this technique is that a modal model can be generated while the structure is under operating conditions. That is, a model within true boundary conditions and actual force and vibration levels caused by ambient excitation, like wind, waves or traffic. Dynamic load testing of bridges, as an important part of the acceptance process for new bridges, is performed under principles of output-only modal testing. Examples of dynamic load testing of bridges presented in this paper show that the peak picking technique is used on site to make a quality check of the aquired data and to judge the overall dynamic charactersistic of the investigated structure.

REFERENCES

[1] A. Cunha, E. Caetano, "Experimental modal analysis of civil engineering structures", *Sound and Vibration,* June 2006.

[2] L. Zhang, R. Brincker, P. Andersen, „An overview of operational modal analysis: major development and issues“ *Proc. 1st International Operational Modal Analysis Conference*, 2005, Copenhagen, Denmark, pp. 179-190.

[3] M. Batel, “Operational modal analysis-another way of dioing modal testing”, *Sound and Vibration,* August 2002.

[4] W. X. Ren, Z. H. Zong, “Output-only modal parameter identification of civil engineering structures”, *Structural Engineering and Machanics*, Vol. 17, No. 3-4, 2004.

[5] R. Brinker, L. Zhang, P. Andersen, „Modal identification from ambient response using frequency domain decomposition“, *Proc. 18th IMAC,* San Antonio, TX, USA, 2000.

[6] H. Herlufsen, P. Andersen, S. Gade, N. Møller, “Identification Techniques for Operational Modal Analysis – An Overview and Practical Experiences” *Proc. 24th IMAC*, St. Louis, Missouri, USA, 2006.

[7] “Ispitivanje mostova probnim opterećenjem / Testing of bridges with test load”, Standard JUS U.M1.046, 1984.

[8] O. Burdet, S. Corthay, “Dynamic load testing of Swiss bridges”, Proc. *IABSE Symposium*, San Francisco, 1995.

[9] V. Golubović-Bugarski, “Dinamičko ispitivanje mosta preko rijeke Vrbas”, Mašinski fakultet Banja Luka, 2009.

[10] V. Golubović-Bugarski, “Dinamičko ispitivanje pasarele u Bulevaru Desnake Maksimović”, Mašinski fakultet Banja Luka, 2009.

[11] N. Đuranović, “Ispitivanje vibracija pješačkih mostova", Ceste i mostovi, No. 5-6, pp. 131-140, Hrvatsko društvo za ceste, Zagreb, 2002.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

DEVELOPMENT TESTING OF VIBRATIONS ON THE HELICOPTER WITH AUTOMATIC WEAPON

Snežana Jovanović [1], *Zdravko Banjac*[2]

[1] Technical test center, Belgrade, e-mail: sneza.jovanovic.toc@gmail.com
[2] Yugoimport FDSP, Belgrade

Abstract - *An example of vibrations measurement on the combat helicopter, in the scope of development testing of installation of the suspension pod with automatic weapon, is given in this paper.*

The vibrations on helicopter during flight, and also during burst fire, were measured. The level and characteristic frequencies of vibrations were obtained in the analysis, upon which the influence of the installed weapon on helicopter structure stability was assessed.

1. INTRODUCTION

In the process of development tests of prototypes quality, the methodology of consideration and analysis of indirect and direct physical values is constantly improved, in order to accelerate and improve the development. Highly sophisticated measurement equipment, accompanied with the software for processing and analysis of the measured values, enables direct and post process visualization of all occurrences caused by stresses in extreme examining conditions. The object of this development testing is the helicopter suspension pod with weapon, which is suspended under standard helicopter stores carrier.

The goal of this part of the examination is checking the vibrations that are transferred from the pod to the helicopter carrier and associated structure, as well as analysis of the influence of vibrations on the stability of the craft structure..

2. TESTING AND MEASURING METHODS

A requirement in the flight examination program of the helicopter equipped with a pod is to check the influence of the arising vibrations, caused by fire from the automatic weapon, on the performances and structure of the helicopter, as well as on the crew. In order to fulfill the requirement related to all influences, the vibrations are measured in a wide frequency scope.

From the point of view of the maximum influence of vibrations on the human body the low frequency scope is applicable (LF up to 80Hz).

The main frequencies during helicopter operation (connected to the Rpm of the main and tail rotors and blade passing frequency) as well as the forcing frequency (automatic weapon fire) are in the LF scope (up to 100Hz). Vibrations produced by the engine operation, transmission, gears and bearings have characteristic frequencies in the scope of medium and high frequencies.

A spectrum of vibration signals from the structure, excited by weapon fire, has remarkable appearances in all the frequency scopes.

Measurements during the flight were carried out simultaneously on several measuring points: from the aspect of the influence of transfer of vibrations from the pod to the helicopter carrier the three measuring points for accelerometers were chosen, and for their influence on the helicopter structure a measuring point in the transport part of the helicopter was chosen. Before measurement of vibrations during flight and installation of the weapon onto helicopter, several measurements of recoil force and vibrations were done on the weapon pod mounted on a trial stand, which was partially helpful in analyzing the measurement results obtained during flight.

Before flight measurements, the adapters for accelerometers were fitted to the chosen measuring points, and the measuring software input/output configuration was calibrated and adjusted.

Contemporary measuring equipment, with which the measurement was done, enabled online monitoring of the relevant parameters having sufficient data rate, and memorizing the long duration flight with all the accompanying occurrences.

The following measuring instruments and software were used:

- Measuring system for vibrations, NetdB12 (01dB Metravib), supported by software for measurement and data processing, dBFA Suite,
- Piezzo accelerometers, CTC, model AC 131-1A and AC 135-1A (of adequate frequency scope and sensitivity),
- Measuring and amplification system MGCplus (HBM) with software CATMAN
- Force transducer U2 1t (HBM) and
- Device for measurement of human exposure to vibrations, with adapters for seats and hands, Maestro (01dB Metravib).

The accelerometers used, according to declared characteristics, satisfy covering of low frequencies (AC 135-

1A) that are related to the helicopter itself, and also high frequencies (AC 131-1A) that are related to transient signals of a single shot.

The trial was done on the test ground of the Serbian Army, in static and dynamic conditions.

This paper presents and provides the analysis of the measurement carried out in the flight of the helicopter fitted with a pod with an automatic weapon.

The weapon (12.7mm machine gun) in the pod is assembled with a recoil force reduction device, while the pod itself has a rigid connection to the helicopter stores carrier.

The accelerometers points were as follows:

1. Measuring point (MP1, first channel on measuring system NetdB12) – accelerometer on longitudinal **X** axis of the pod,
2. Measuring point (MP2, second channel) – accelerometer on transversal **Y** axis in the transport part of the helicopter,
3. Measuring point (MP3, third channel) – accelerometer on **X** axis of the rear connection, of the rear weapon support and
4. Measuring point (MP4, fourth channel) – accelerometer on vertical **Z** axis of the pod, at the rear weapon support.

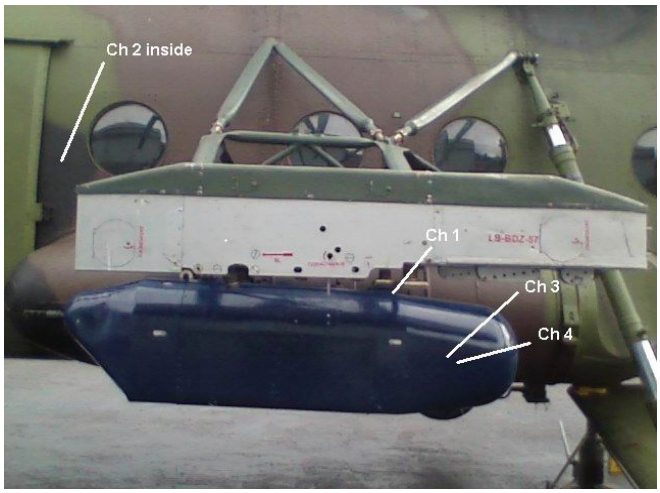


Fig. 1 *Suspension pod with machine gun and measuring points*

The trial flight lasted 23 minutes, out of which 9 minutes were spent on firing at a target, with breaks between bursts.

Firing at a target was done according to the following schedule:

1. First shot – burst of 7 rounds lasted 700 ms (781.4 s÷ 782.1 s from the flight start, i.e. beginning of the measured data acquisition),
2. Second shot – burst of 7 rounds, lasted 1000 ms (914.4 s÷ 915.2 s),
3. Third shot – burst of 9 rounds, lasted 1000 ms (916.05 ÷ 917.25 s),
4. Fourth shot – burst of 2 rounds, lasted 300 ms (1063.6 s÷ 1063.9 s),
5. Fifth shot – continuous burst of 56 rounds lasted 5330 ms (1198.55 s÷ 1204 s) and
6. Sixth shot – continuous burst of 62 rounds lasted 6000 ms (1299.8 s÷ 1305.9 s from the flight start, i.e. beginning of the measured data acquisition).

Acquisition of measured data was done and memorized in one measuring session for the entire flight (23 min), and afterwards, the parts of signals related to the periods before and after fire and each burst, were cut and analyzed.

Besides the measurement of these vibrations, during the same flight, the LF vibrations were measured on measuring point of passengers in helicopter, from the point of view of human comfort and health risk.

2.1 Results of examination - analysis

In post processing of memorized data, the vibrations expressed in acceleration amplitude (m/s^2) as a function of real time (seconds) were obtained.

For the purpose of frequency analysis of the vibrations of helicopter equipped with weapon and influence of the accented transient signals of single shot on craft, the spectrums of characteristic appearances were done.

For the spectrums of shot signals (up to 5 kHz) a natural narrow band filter FFT was done (by application of rectangular window suitable for transient shot signals), with maximum possible number of lines and number of averaging with respect to duration and rate of measurement.

The same filter is used for vibration diagnostic area and for spectrums of LF vibrations of the helicopter, but with the Hanning window. In spectrums, the axes are in linear scale for HF vibrations and in logarithmic scale for LF vibrations, for the purpose of easier recognition and displaying of characteristic frequencies (acceleration has RMS values).

From the aspect of influence of fire on the helicopter, and for the purpose of obtaining the characteristics of basic modes of the pod-helicopter system, processing of signals for the entire burst of 62 rounds was done for channels 1 and 4, as well as for the period of calming down of the structure after last round was fired (to achieve this, the end of burst signal was filtered by low pass filter of 100 Hz).

From the point of view of the influence on the crew the entire flight signal on the measuring point 2 was processed, as well as the signal for MP on the seat with the special adapter with three axes accelerometer in it.

For the purpose of simpler display and clearer representation of the large quantity of results, the table results are presented, and are related to maximum and apparent values of the measured magnitudes, while all comprising values are better presented in graphics. All necessary explanations are also contained in Table 1.

Table 1 *Results of testing during helicopter flight experiment*

Measuring point	Measuring session	Vibrations amplitude Max acceler. (**m/s^2**)	Freq. max RMS (**Hz**)
Ch 1, MP1, **X** axis of the pod	10 s before first shot	7	16.3; 205; 102...
	1. shot: burst of 7 rounds	500	712; 1400; 2700...
	2. shot: burst of 7 rounds	400	681; 1780; 220...
	3. shot: burst of 9 rounds	700	731; 1150; 1700...
	4. shot: burst of 2 rounds	300	712; 550; 1700
	5. shot:, burst of 56 rounds	600	687; 131
	6. shot: burst of 62 rounds	600	687
	10 s after last shot	8	16; 68; 102; 202...
	Outstanding levels in the signal of no fire cause, on the helicopter frequencies	1) 50 m/s^2, lasts 752s ÷752s 2) 4200 m/s^2, lasts 1101s÷1101s 3) 45 m/s^2, lasts 1165s ÷ 165s 4) 25 m/s^2, lasts 1278s ÷ 1278s	687; 1856;… 16.2; 101….
Ch 2, MP2, **Y** axis in the transport part of helicopter	10 s before first shot	30	102; 205; 16...
	1. shot: burst of 7 rounds	1000	993; 887...
	2. shot: burst of 7 rounds	1150	887...
	3. shot: burst of 9 rounds	850	537; 887...
	4. shot: burst of 2 rounds	800	531...
	5. shot: burst of 56 rounds	850	887; 528...
	6. shot: burst of 62 rounds	1000	887; 528; 159...
	10 s after last shot	30	102; 16; 64; 128; 205...
	Outstanding levels in the signal of no fire cause	Not remarkable	
Ch 3, MP3, **X** axis of the rear weapon support	10 s before first shot	10	16.1; 102; 205...
	1. shot: burst of 7 rounds	450	677...
	2. shot: burst of 7 rounds	400	678...
	3. shot: burst of 9 rounds	600	780...
	4. shot: burst of 2 rounds	270	680...
	5. shot: burst of 56 rounds	800	680...
	6. shot: burst of 62 rounds	1200	1580...
	10 s after last shot	10	16...
	Outstanding levels in the signal of no fire cause	1) 50 m/s^2, lasts 752s÷752s 2) 60 m/s^2, lasts 1165s÷116s 3) 35 m/s^2, lasts 1278s÷1278s	687; 1856;… 16.2; 101….
Ch 4, MP4, **Z** axis of the rear weapon support	10 s before first shot	10	82; 16...
	1. shot: burst of 7 rounds	600	969; 1650; 663...
	2. shot: burst of 7 rounds	500	1526...
	3. shot: burst of 9 rounds	500	1037; 62...
	4. shot: burst of 2 rounds	350	1407...
	5. shot: burst of 56 rounds	1700	1375...
	6. shot: burst of 62 rounds	1700	1375...
	10 s after last shot	12	16; 63...
	Outstanding levels in the signal of no fire cause	1) 50 m/s^2, lasts 752s÷752s 2) 82 m/s^2, lasts 1165s÷1165s 3) 38 m/s^2, lasts 1278s÷1278s	687; 1856;… 16.2; 101….

A part of the measurement results analysis is graphically presented in the following figures, relating to the following chosen units:

- Measuring point 1 (Ch 1), continuous fire during helicopter flight, last burst – 62 rounds
- Measuring point 2 (Ch 2), analyzed 10s before and after a period of fire lasting 9 min,
- Measuring point 4 (Ch 4), analyzed the same part of the flight, the same burst as in the case of MP 1 (Ch 1),
- Involving the measured force in burst fire, measured on the pod with the same gun before installation on the helicopter, on the place corresponding to MP 1 and
- Measuring point of the crew seat, an exposure to vibrations is analyzed as well as comfortableness.

The analysis of last burst of 62 rounds, lasting 6000 ms (1299.8 s - 1305.9 s) of the flight time signal, on measuring point 1 (Ch 1) is presented in fig. 2.

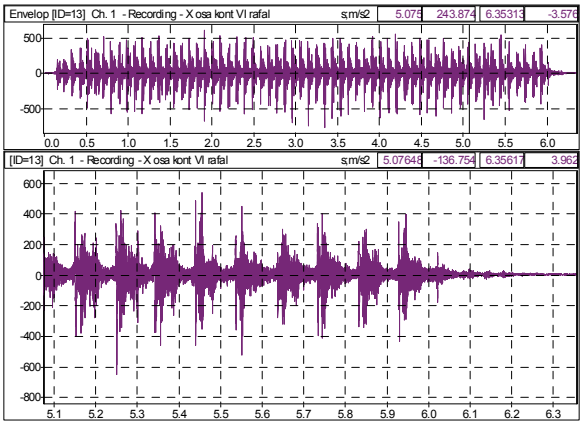


Fig. 2 *The burst of 62 rounds (up) and the last 9 rounds (down) on MP 1*

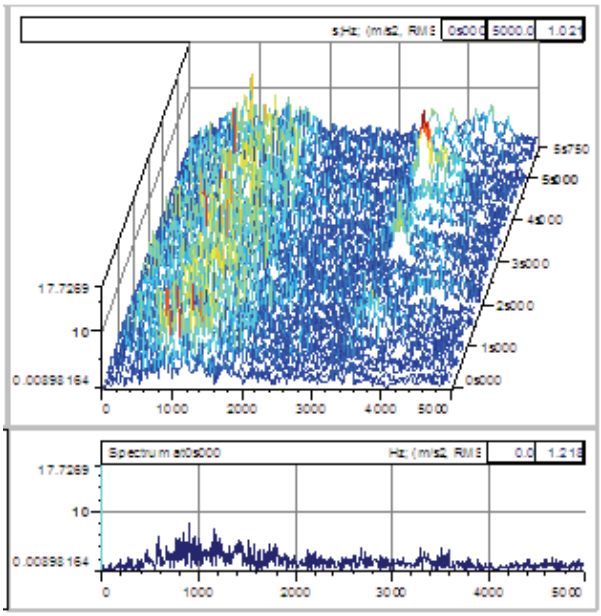


Fig. 3 *Complete flight signal spectrum on MP 1*

The last part of the signal in that burst (after the last single shot) was particularly analyzed, in order to see the behavior of the excited structure (system pod-helicopter) in the phase of calming down and pure oscillations, fig. 4 ÷ 7.

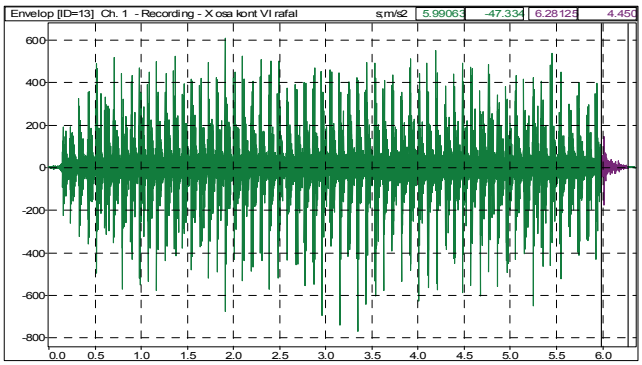


Fig. 4 *The ending part of the burst, particularly analyzed, on MP 1*

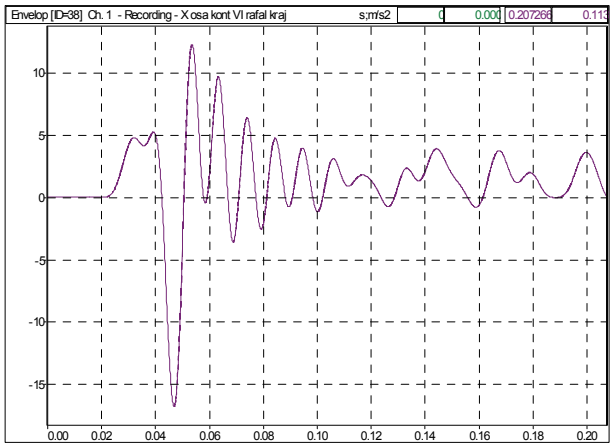


Fig. 5 *Filtered signal of the ending part of burst, up to 100 Hz, on MP 1*

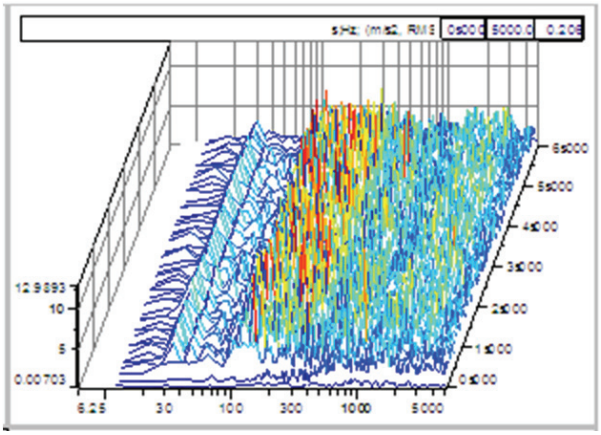


Fig. 6 *3D spectrum of the ending part of burst, MP 1*

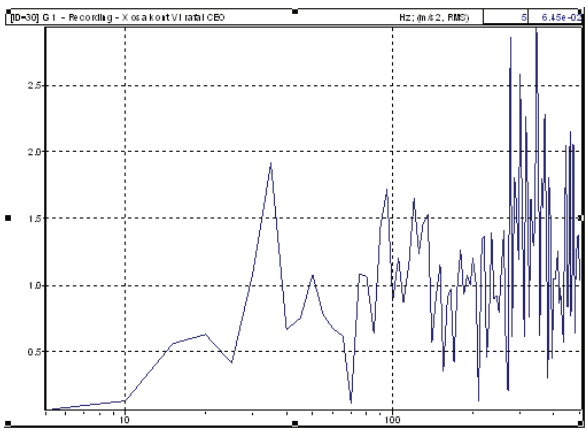


Fig. 7 *The spectrum(log; NF) of the end of burst MP 1*

The diagram in fig. 8 shows the acceleration signal for measuring point 2 inside the helicopter (Ch2). It is apparent that there are no remarkable levels in between bursts and before firing, which appear in the rest of the measuring points (on the pod). These signals before fire and in between bursts, given in the table 1, are caused by reloading the first round, as well as by reloading after stoppage in the burst 4. High level of acceleration in the channel 1 at time 1101.456 s-1101.458 s (2 ms) is probably caused by the breech release with no fire (misfire), followed by a new reloading (1278 s).

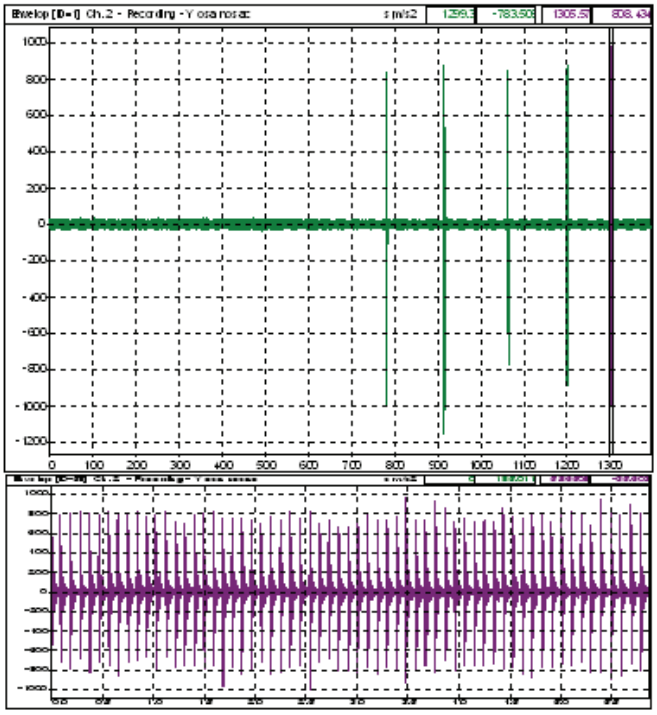


Fig. 8 *Complete flight signal on the MP 2 and burst No 6 analyzed*

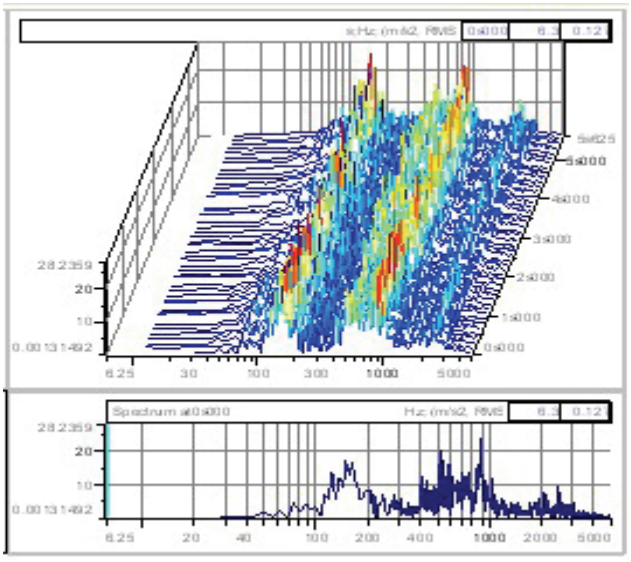


Fig. 9 *The spectrum of complete burst 6 on MP 2*

Because of the interest in the LF scope, the period of 10s before fire is particularly analyzed (771.4 s– 781.4 s), since the transport part of the helicopter is in question. After that, in order to see the possible changes in the equivalent level and spectrum, and for the purpose of comparison, the period of 10 s after fire was analyzed.

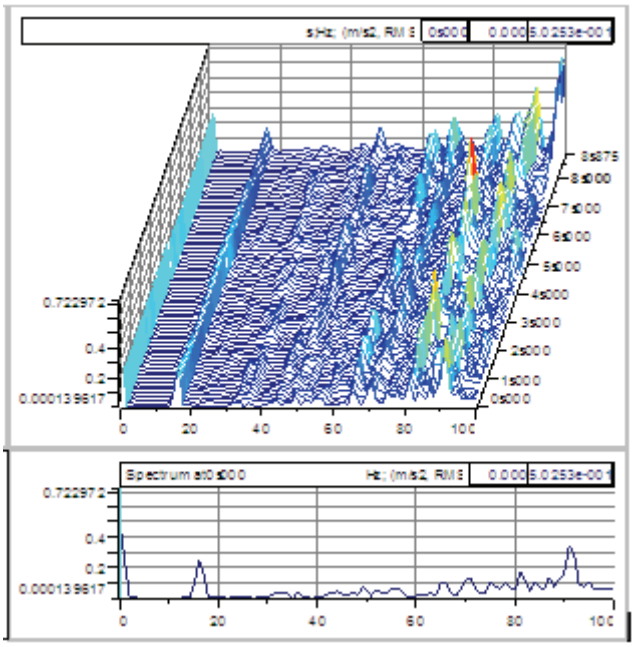


Fig. 10 *The spectrum of filtered signal in the period of 10 s before fire, up to 100 Hz, on MP 2*

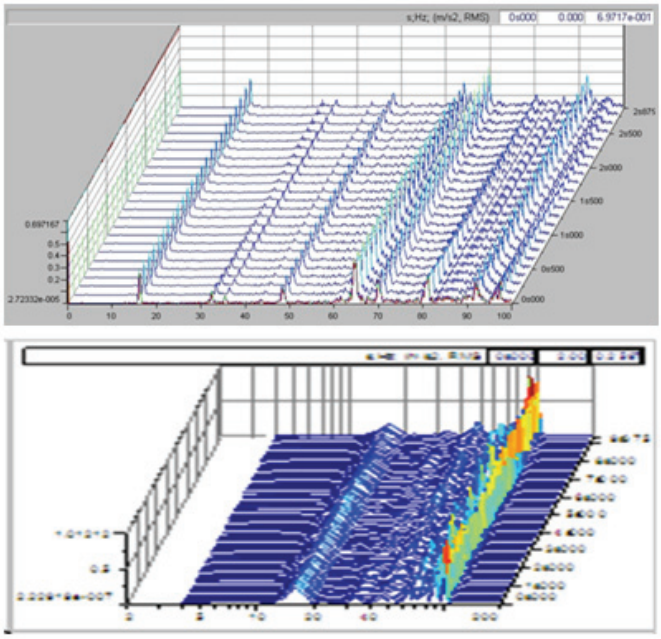


Fig. 11 *The spectrum of filtered flight signal in the period of 10 s after fire, linear and log scale, MP 2*

The diagram in fig. 12 shows the same burst as in the previous case, but for the measuring point 4 (vertical axis on the rear weapon support), where increasing of the signal to a level of 1700 m/s^2 up to the middle of the burst (app. 30 rounds) is apparent, and after that it is sustained about that level.

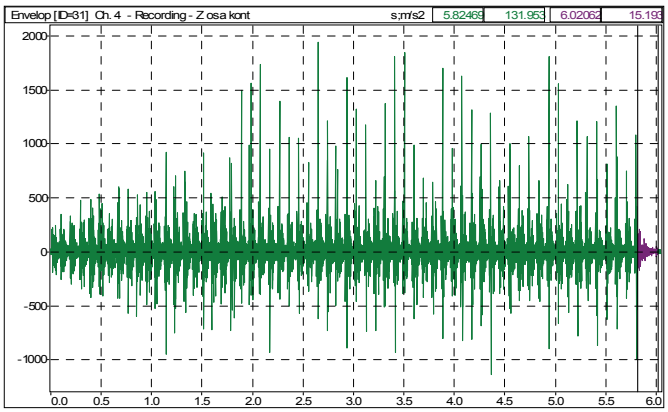


Fig. 12 *The burst of 62 rounds on MP 4; the part after the last round fired is marked for particular analysis*

This is characteristic for channel 4, since there are significant local elastic deformations of the surrounding structure of the weapon support on that point.

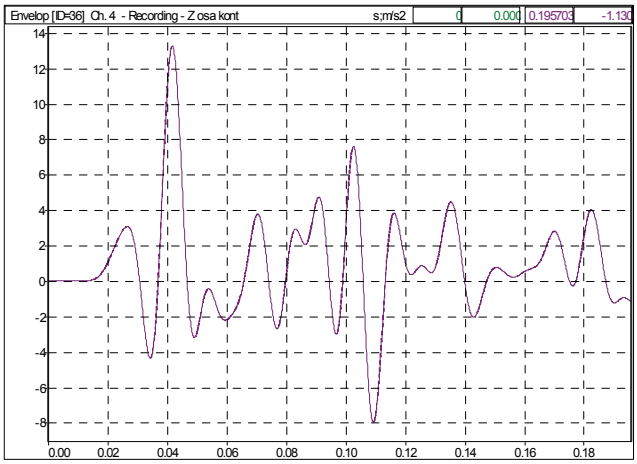


Fig. 13 *Filtered signal of the ending part of source signal of the burst, up to 100 Hz, on MP 4*

This measurement of the vibrations in flight was preceded by the measurement of recoiling force that is transferred from the pod to the helicopter structure via stores carrier, when firing from the trial stand on the ground (fig. 14).

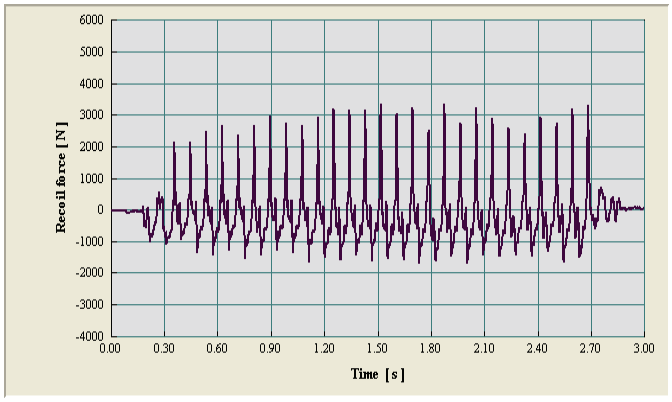


Fig. 14 *The recoiling force in burst fire, measured on the pod with the machine gun, before its installation into the helicopter; it corresponds to the MP 1 from this measurement*

On the diagram, fig. 14, a change of the force during burst is shown, where the following is remarkable:

- The change in force is double directional (backwards and forward) and slightly varies in amplitude from round to round,
- The process is stable, i.e. there is no amplification of the signal during burst, independently of the burst length.

On the diagram, fig. 15, the spectrum of measured force is shown.

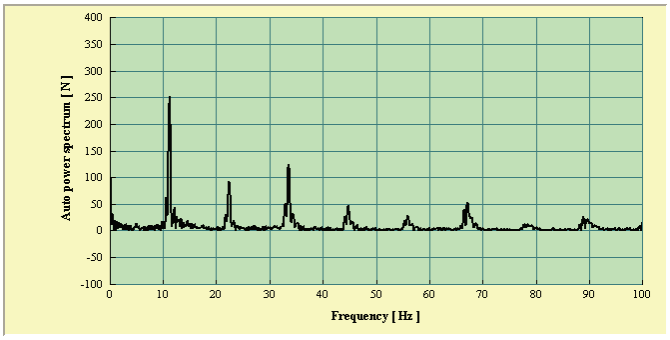


Fig. 15 *The spectrum of recoil force during burst, measured on the pod with machine gun before installation onto the helicopter, corresponds to MP 1*

By comparison of the recoil force in case of fire from the test stand with the acceleration change on measuring points it is obvious that all oscillating forms of the structure are much faster than the forcing frequency, i.e. that the oscillation of the structure calms down before firing the new round. That implies a conclusion that the work of weapon on helicopter is also stable, i.e. that there is no amplification of the level of force and acceleration on helicopter.

Characteristic magnitudes in this process are:

- Natural frequency of oscillation of the gun barrel (that is not determined for this gun in this occasion)
- Resonant frequency of the pod in vertical axis, suspended on trial stand, is 23 Hz
- Natural frequency of the pod together with the supporting structure of the helicopter in longitudinal axis is 35 Hz (first) and 96 Hz (second)
- Forcing frequency, i.e. rate of fire of the machine gun, is 11 Hz.

Based on these data, it is obvious that there are no conditions for the resonance of the system pod-helicopter, which is confirmed by the measurement.

The results from the measured vibrations in three axes on the crew seat, are related to the period of fire of 9 min that includes the period of fire with breaks and the flight period after that.

During the complete flight the exposure overpasses a limit of warning level, but is far less than limit level. The magnitude relating to the comfort is rather in the uncomfortable scope, which is characteristic of helicopters.

3. CONCLUSION

Based on the analysis of measurement results, after post processing of the measured time signals, and on the analysis of their spectrums, there are no grounds for discussion about resonance, but the stability and material fatigue of the structure exposed to large amplitudes of vibrations during the fire can be discussed. In that sense, the parts of signals for the periods of 10 s before fire and 10 s after fire were particularly considered and compared, for each measuring point.

Based on the measurement results, it is concluded that the use of the machine gun pod does not produce undesired consequences for the crew and for the craft structure during fire, and can normally be used, from the point of view of vibrations.

Suggestion: Since the levels and the frequencies of shocks to the helicopter structure parts in real conditions during the fire of weapon are now known, an accelerated fatigue examination of that part of material can be performed in laboratory conditions of the Test Center, on shock and jolting machines.

REFERENCES

[1] SORS 0514-1A, Вибрације – Услови испитивања ваздухопловне опреме и наоружања у условима примене, 1981.

[2] J. Fries, Helicopter Forced Response Vibration Analysis RTVIB20, ARL-TR-75, U.S.Army Research Laboratory, MD, 1992.

[3] ISO 2631-5, Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration – Method for evaluation of vibration containing multiple shocks 15.02.2004.

[4] D. Novak and T. R., Teorija leta helikoptera, Zagreb: Sveuciliste Zagreb, Fakultet prometnih znanosti, 2012.



University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

VIBRATIONS OF RAILWAY AS A CAUSE OF NOISE DUE TO RAILWAY TRANSPORT

Mirza Hadzimujović[1], Sandra Šaković[2], Biljana Mladenović[3]

[1] State University of Novi Pazar, Department of Technical Sciences
[2] University of Niš, High Technical School, sandrasakovic@hotmail.com
[3] University of Niš, the Faculty of Civil Engineering and Architecture

Abstract – *In this paper, on the example of the railway line Belgrade (Batajnica)-Stara Pazova-Šid-Croatian border the vibration level expressed in (mm/s) and (Vdb) at a distance of 0 to 50 meters at a speed of v = 50, 70, 100 and 120 km/h is shown for the current state of the typical cross sections. Further, the impact of traffic noise and vibration in the phase of reconstruction and modernization of the observed railway line on the environment at a speed of v=120 km/h and v = 160 km/h is discussed. Special attention is paid to the impact of the superstructure on the noise emission. It is pointed to the need for adequate maintenance of the superstructure and substructure and reduction of noise in the region of the railway line.*

1. INTRODUCTION

Noise is, referring to the most commonly used definition, any unwanted sound [1]. Noise has the same characteristics as the sound, but the difference is that it causes various psychophysical sensations (disorders, anxiety, vulnerability) and has a harmful effect on human health. Noise is sound that disturbs, upsets and damages the physical and psycho-physiological functions of the organs of a human body. In real terms, the noise is just a subjective experience of sound as physical phenomena. In fact, the sound becomes noise only when there is an individual who is disturbed by that sound.

Sound vibrations, i.e. sound becomes under the influence of external forces, which takes particles of elastic medium out of the equilibrium position and cause them to an oscillatory motion about the equilibrium position. External force that causes a disorder of the medium is called sound source, i.e. each body that causes mechanical vibrations at the same time generates sound energy to the particles of elastic medium and transmits it to the immediate vicinity. In this case, these are vibrations of a rigid body, i.e. thresholds and other elements of railway superstructure, where lie and are fasten the rails, along which the wheels of locomotives and wagons are moving [2]. Due to the weight and irregularities along the railway, at different velocity range different deflections occur, which produce sounds of varying intensity that is noise. In general, the following position is possible for the line of railway passenger subsystems regarding the ground: below terrain surface (deep or shallow tunnel, cut), on the terrain surface (at street level) above the terrain (embankment, cascade). The order of listing the possible positions of the track in relation to the terrain corresponds to the growth of expected adverse impact on the environment in terms of noise and vibration [3].

2. IMPACT OF SUPERSTRUCTURE ON NOISE EMISSION

Construction of superstructure generally must satisfy the usual requirements of a favorable transfer of static and dynamic load, with respect of the principle of stress minimizing, going from the rail to substructure, as well as requirements for the safe conduct of the rail vehicle [4]. Therefore, new railway terminals are designed as transit type in order to occupy less area of a city site, and the greatest sources of noise to be moved to underground. In application are two modified constructions of the superstructure in the urban environment: rails on the groundwork of crushed stone and rails on the laminated solid surface. The environment conditions are primarily defined by the design of superstructure and substructure of the railway, so that the noise and vibration level that are emitted into the environment has to be in accordance with design parameters. Maintenance work on rails on the groundwork of crushed stone becomes a particular problem in heavy daily traffic, and must be maintained at night. Reduction of noise and vibration is achieved using elastic rail damper system [5], [6], reducing the distance between thresholds or otherwise. Construction of track with continuous elastically supported rails on a solid surface is characterized by lower emission of noise and vibration comparing to construction with directly supported elastic rails. In addition to standard protective measures against noise, the elements for noise absorption are applied and other ways of noise reduction, as well.

Wrinkling of the upper surface of the rail head is a common cause of irregularities on the surface on which the rail wheel is rolling. The phenomenon is observed as a periodic irregularity of the longitudinal profile of the rail head in the form of bright bulges and dark dents, [6]. By grinding, in addition to wrinkling, phenomena on the surface of rail head that are the result of fatigue of steel are eliminated. The strategy of grinding involves preventive, corrective and cyclic activities.

It is considered that the potential for reducing the noise level based on care of the rails ranges from 15 to 20 dB(A) compared to rails which is not taken care of.

The goal of grinding is an extension of the life-time of the rails in track, reducing of the total cost of maintenance of the track and vehicles, and reducing the level of noise and vibration emission from railway traffic.

3. THE EXISTING LEVEL OF VIBRATION ON THE CROSS SECTIONS OF THE RAILWAY BELGRADE (BATAJNICA) - STARA PAZOVA - ŠID - BORDER OF CROATIA

3.1 The influence of vibration level on the noise level, depending on the speed

Vibrations, arisen as a result of contact wheel to rail, are one of the important criteria that characterize the relationship between railway and the environment. As for importance of this criterion, regarding limitation of its spatial effects, it is not a significant problem in terms of the environment. Analyses of vibration level, as well as potential impacts, were performed according to the methodology of the Department of transportation, Federal Transit Administration, (US DOT, FTA, 1995.**Error! Reference source not found.**.

By analyzing the observed railway corridor: Belgrade (Botanical) - Stare Pagoda - Did - Croatian border and using the model to determine the vibration level, it was found that the railway runs partly through areas in which there are located only residential buildings, i.e. buildings from the "Category 2", in which permitted levels of vibration is 0.2 mm/s for frequency occurrences, or 0.5 mm/s for the rare occurrences. According to the existing traffic parameters, characteristics of rails specified places – mile marks, vibration levels that occur in the monitored intersections of the corridor are obtained by computation and shown in Table 1, **Error! Reference source not found.**.

Table 1 *Existing vibration levels on the typical railway line sections; Belgrade (Batajnica)-Stara Pazova-Sid-Croatian border railway line, as a result of railway traffic for speeds: v=50; 70; 100 and 120km/h*

Distance (m)	0	1	3	5	10	15	20	25	30	50
Vibration level (mm/s)	2.48	2.06	1.50	1.15	0.71	0.51	0.39	0.31	0.25	0.15
Vibration level (VdB)	93.9	92.3	89.5	87.2	83.0	80.1	77.8	75.8	74.0	69.3

Distance (m)	0	1	3	5	10	15	20	25	30	50
Vibration level (mm/s)	3.48	2.89	2.10	1.61	0.99	0.71	0.54	0.43	0.35	0.20
Nivo vibracija (VdB)	96.8	95.2	92.4	90.2	86.0	83.0	80.7	78.7	76.9	72.2

Distance (m)	0	1	3	5	10	15	20	25	30	50
Vibration level (mm/s)	4.98	4.14	3.00	2.31	1.42	1.02	0.78	0.62	0.50	0.29
Vibration level (VdB)	100.0	98.4	95.6	93.3	89.1	86.2	83.9	81.8	80.1	75.4

Distance (m)	0	1	3	5	10	15	20	25	30	50
Vibration level (mm/s)	6.54	5.43	3.94	3.03	1.87	1.34	1.02	0.81	0.66	0.38
Vibration level (VdB)	102.3	100.7	97.9	95.7	91.5	88.5	86.2	84.2	82.4	77.7

3.2 The impact of traffic noise and vibration on the environment in the phase of reconstruction and modernization of the observed railway line

The impact of the railway on the environment during construction works of its modernization depends on several factors: the technology of works, management on the construction site, natural resources, energy resources, etc., and is temporary in nature, with no greater adverse impacts on the environment.

3.2.1 Vibrations

The negative impact of vibration on structures is manifested mainly through the fatigue of material, reduction of the life–time of a building, and as for humans, through direct mechanical effects on the body by changing the acceleration and as secondary, through irritation, in biological and psychological sense. Calculation of vibration level after the completion of modernization of the railway section: Belgrade (Batajnica)-Stara Pazova-Šid-Croatian border, was carried out using the same model as in the case of the vibration level of the existing situation, and the results are given in the Table 2.

In the Table 2, it can be seen that the limit speed for the rare occurrence of vibration (0.5 mm/s) is reached at a distance in the range of 7m to 21m, and for the frequent occurrence (0.2mm/s) at distances ranging from 19m to 42m, measured from the track axis **Error! Reference source not found.**.

Table 2 *Simulated values of vibrations levels troughout the design period (up to 2030) on the modernized railway line Beograd (Batajnica) -Stara Pazova-Šid- Croacia border , as a result of railway traffic for speeds v=120 and 160km/h.*

Distance (m)	0	1	3	5	10	15	20	25	30	50
Vibration level (mm/s)	1.16	0.97	0.70	0.54	0.33	0.24	0.18	0.14	0.12	0.07
Vibration level (VdB)	87.3	85.7	82.9	80.7	76.5	73.5	71.2	69.2	67.4	62.7

Distance (m)	0	1	3	5	10	15	20	25	30	50
Vibration level (mm/s)	3.23	2.68	1.95	1.50	0.92	0.66	0.51	0.40	0.33	0.19
Vibration level (VdB)	96.2	94.6	91.8	89.5	85.3	82.4	80.1	78.1	76.3	71.6

By comparison of the obtained results (Table 2. and Table 4.) it can be concluded that the level of vibration will be reduced in addition to the increased train speed after modernization of the railway line Belgrade (Batajnica) - Stara Pazova - Šid-Croatian border, as well as by overhaul of existing and acquisition of new trains.

3.2.2 Protective measures against vibration

Based on the results of the calculation of vibration due to the influence of railway transport in the observed corridor, it can be concluded that the modernization of the railway line Belgrade (Batajnica) - Stara Pazova – Sid - Croatian border will reduce vibration and that no special protection measures against vibrations are needed.

4. CONCLUSION

As the noise is unwanted sound, i.e. sound that causes psychological sensations that arise under the influence of external forces, in this case the motion of the train, whose weight can reach more than 1000 tons, along the railway. There are many factors that influence noise during the rolling of wheels along the rails, but of particular importance is the deflection that occurs on the rails at different speeds. In the paper are shown the vibration levels (mm/s) and (VDB) at a distance of 0 to 50 m from the axis of the track, at speeds of 50, 70, 100 and 120 km/h. Before reconstruction values of vibration level were: 2.48 mm/s to 6.54 mm/s and 93 Vdb to 103.2 Vdb, respectively, at the distance of 0 (zero), and of 0.15 mm/s to 0.38 mm/s and 69.3 VdB to 77.7 VdB, respectively, at the distance of 50 m.

The following values were obtained for the case after the modernization of the considered railway line at speeds of 120 and 160 km/h, respectively: the level of vibration is 1.16 mm/s and 3.23 mm/s and 87.3 Vdb and 96.2 Vdb at the distance 0 (zero), and 0.07 mm/s and 0.19 mm/s and 62.7 Vdb and 71.6 Vdb at the distance of 50 m.

Based on the above it can be concluded that the modernization of the railway has reduced vibration level and that no special protection from vibrations is necessary.

Acknowledgement: This research is conducted at The Faculty of Civil Engineering and Architecture of University of Niš in the framework of the projects in the field of technological development in the period 2011-2014, and titled "Experimental and theoretical investigation of frames and plates with semi-rigid connections from the view of the second order theory and stability analysis" (TR 36016) and "Development and improvement of methods for analyses of soil-structure interaction based on theoretical and experimental research " (TR 36028), financially supported by the Ministry of Education, Science and Technological Develpment of the Republic of Serbia.

REFERENCES

[1] D. Cvetković, M. Praščević: *Buka i vibracije,* Univerzitet u Nišu, FZNR, Niš, 2005.

[2] Z. Popović, L. Puzavac, L. Lazarević, „Šinski sistemi i zaštita urbanog okruženja od buke”*, Ecologica“*, Volume 18(63), str. 434-438, 2011.

[3] Nowack, R.: *Elastische Schienenbefestigungssysteme als schallminderde Manahme bei Stahlbricken ohne Sctotterbet.* ETR, 1998, 47: H 4, pp.. 215-222

[4] Z. Popović, L. Puzavac, L. Lazarević, „Značaj železničke infrastrukture u upravljanju bukom“, *2nd International Scientific meeting, GTZ 2012*, Tuzla, pp. 1121-1128

[5] *Zakon o zaštiti životne sredine* (Sl. Glasnik RS, br.135/04)

[6] W. Schöch, “Entwicklung von Schleistrategien gegen Rollkontakt termüdung – Ein international Überblick”, *Zevrail Glasers Annallen*, 132, pp. 2-10, 2008

[7] Saobraćajni institut CIP, *Prethodna analiza modernizacije železničke pruge: Beograd - Stara Pazova – Šid - Gr. Hrvatske na životnu sredinu*, Beograd, 2007.

[8] Z. Isakov: “Uticaj modernizacije železničke pruge Beograd-Stara Pazova-Šid-Gr. Hrvatske, na životnu sredinu”, VI naučno stručno savetovanje, *Ocena stanja, održavanje i sanacija građevinskih objekata i naselja. SGIS*, Divčibare 2009, str: 525-530



University of Nis
Faculty of Occupational Safety

„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

RESEARCHING THE EFFECTS OF MOTORCYCLE'S VIBRATIONAL PROCESSES ON SAFE DRIVE

Branislav Aleksandrovic[1], Rajko Radonjic[1], Aleksandra Jankovic[1]

[1] Faculty of Engineering, University of Kragujevac, Serbia, bane1510@yahoo.com

Abstract - *In this paper are being emphasized actual problems and demands regarding safe drive of single-track vehicles under road and off-road traffic conditions. It is emphasized a particular behavior occurred during single-track vehicle researching. For particular researching of motorcycle's behavior under short-term impulse character excitation, a simulation model is created in order to investigate vibration processes from both, comfortability and safety point of view. Obtained results were submitted and analyzed and the criteria for the evaluation of quality of motorcycle's behavior were defined in the terms of its actual design and application demands.*

1. INTRODUCTION

In road traffic one can meet vehicles with various design concepts and various characteristics. According to the number of the tracks and wheels, all cars can be classified into the single-track and two-wheeled vehicles and into double-track's with four or more than four wheels. More information on the classification and categorization of vehicles is given in the "Regulations on the division of motor vehicles and trailers, and technical requirements for vehicles operating on the roads," as appended norms of traffic safety [1].

Bicycles and motorcycles are two representative categories of single-track vehicles with two wheels, which are encountered in traffic and whose dynamic characteristics in interaction with the driver's behavior significantly affect safety.

The study of the dynamics of single-track vehicles has been conducted for more than 200 years, and significant results in this area have been achieved over the past four decades. Thereby, it could be said that the motion of bicycles and motorcycles has a lot of common features, but that is very different from the motion of double-track vehicles [2].

In numerous papers, published in this scope, various problems are included depending on the actual events in the given period of time. Theoretical analyses involved investigation of rectilinear and curvilinear motion of the vehicle. Mathematical models have been established for rigid or flexible mounting systems, including the effect of the driver, when the driver is passive, as added mass and modified structure and configuration of the entire system, on one side, and while the driver is active, as a steering action using vehicle's command and changing the position of the body relatively to the vehicle, on the other side [3], [4], [5].

Unlike double-track vehicles that do not have the stability to keep the direction of the movement without the help of the driver, the single-track vehicles have neither stability of direction of movement, nor the stability of the position in relation to the road [6].

For these reasons, the role of the driver of single-track vehicles is very complicated and difficult. While driving the driver is getting tired, and frequently he causes the traffic accidents with serious injuries or deaths [7].

Taking in consideration above highlighted problems, in this paper has been considered some particularity of single-track vehicles vibrational processes, especially considering motorcycles compared to double-track vehicles, as well as their influence on the safety drive, both in the road and off-road conditions.

2. SUBJECT OF PAPER

Research of this study above all, should emphasize a complex interaction of motorcycles and the riders in terms of achieving a stable motion of the system and thus obtaining the appropriate safety level in traffic conditions. With these aspects are important optimal design, construction, vehicle maintenance, and adequate training of drivers.

Bearing in mind the different performances and driving characteristics of the vehicle on one side, and the possible regimes of motion and scenarios in traffic on the other side, but also considering the difference in age, temperament and strategy of the drivers, of particular importance for this study is the

selection of appropriate simulation models, then the conditions of motion and dominant factors, in order to make the analysis of their impacts on each other.

Starting from the complex dynamics of the motorcycle as a spatial system, distributed in three oriented planes, it should have been created an adequate model for motorcycle's dynamics analysis with the passive role of the driver. In this way it is created a basis for investigation of vibration effects on a motorcycle (1) the ability to follow the road profile, on road and off-road conditions without transferring (or significantly damped) vibrations on the driver and passenger, therefore, the aspect of driving comfort (2), the conditions necessary to achieve reactive forces in contact tire-road, drive force, brake force, lateral driving force, the economical aspect, dynamics, brake efficiency, the lateral stability (3), the stability of the motorcycle's position, required for various regimes of motion operating under variable speed, along the path of variable curvature.

In accordance with the above listed requirements, in this paper is created a model of the system for analysis of the basic motion along the straight direction, in general case, involving interaction of vertical and longitudinal dynamics of a motorcycle.

2.1 Motorcycle's dynamics modelling

To creating a physical- mathematical models in order to investigate the vibrational process, it was started from the concept and design characteristics of the motorcycle shown in Figure 1.



Figure 1 *Motorcycle*

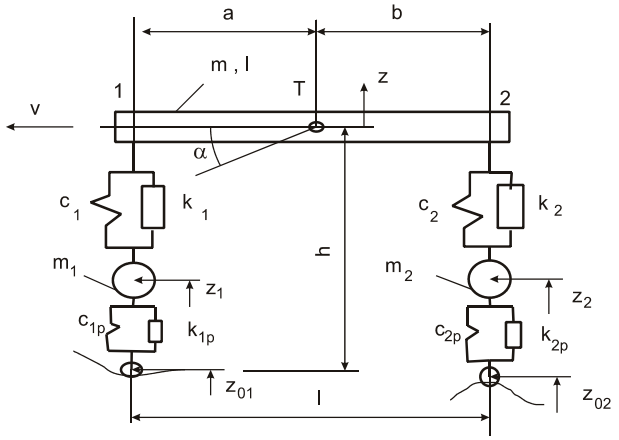


Figure 2 *Vibrational model of motorcycle*

The initial data, expressed in general designations are the following: total own mass, m, the distance between the wheels, l, the center of mass position, T with, the longitudinal coordinates a, b and the height, h, the distribution of weight per wheel, m_1, m_2. Adequate model of this system for the analysis in plane vertical-longitudinal dynamics is shown in Figure 2.

In the general case, the model possess five degrees of freedom: two degrees of freedom for, so called, supported masses m, translation z, rotation α; one degree of freedom per each non-supported masses m_1, z_1, and m_2, z_2 and one degree of freedom of basic, longitudinal motion, velocity v.

Differential equations of motion are obtained from dynamic conditions of equilibrium for the acting forces and moments with respect to the position of static equilibrium, written in the general form (1), (2), for supported masses (3), (4) for each non-supported mass, separately.

$$m \cdot \ddot{z} + F_{ck1} + F_{ck2} = 0 \quad (1)$$

$$-I \cdot \ddot{\alpha} - F_{ck1} \cdot a + F_{ck2} \cdot b = 0 \quad (2)$$

$$m_1 \cdot \ddot{z}_1 - F_{ck1} + F_{pck1} = 0 \quad (3)$$

$$m_2 \cdot \ddot{z}_2 - F_{ck2} + F_{pck2} = 0 \quad (4)$$

where, besides the marks, already given in Figure 2, also the following marks were introduced,

F_{cki} , i=1,2... – resultant of restoring and damping force of the front wheel suspension, and the rear wheel, respectively,

F_{pcki}, i=1,2,... – resultant of restoring and damping force of the front and the rear wheel tires, respectively. Extended expressions of those forces include the influence of stiffness and damping, c_i, k_i, c_{ip}, k_{ip}, according to Figure 2, and they are the functions of relative displacements and the relative velocities of supported and non-supported masses of motorcycle.

It should be emphasized that those are reduced features of elastic suspension system obtained by reducing the real system in the plane of the vertical dynamics. For the above defined

mathematical model, a constant velocity of the longitudinal motion was assumed, for a single simulation realization (step). And the same may be varied from one realization to another in terms of analysis the effects of its changes on the parameters of vibrational processes. Depending on the relationship of structural parameters and, above all, depending on the mass, moment of inertia, mass distribution, the coordinates of the center of mass, stiffness and damping relations of front and rear suspension and the appropriate tires, it is possible to establish different coupling degrees between the fundamental oscillation modes of the system - so in the same way it could be simplified for some specific tasks and researching conditions.

On the basis of the presented oscillation model in Figure 2, a number of simulation studies has been performed, using software developed in the interactive environment of modular blocks and varying parameters.

This paper presents, analyse and illustrates the examples of researching of vibrational motorcycle processes, generated by specific excitation of step and impulse excitation form, in accordance with the structure of identification model with two inputs and four outputs as shown in Figure 3.

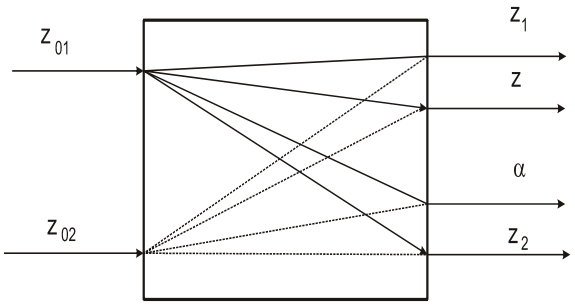


Figure 3 *Identification model of motorcycle*

Thereby, three typical cases were observed:

1. excitation of the front wheel only,
2. excitation of the rear wheel only,
3. excitation of both wheels, with time delay, in accordance with the values of the longitudinal motion velocity and the distance between the wheels.

2.2 Researching results

For the motorcycle shown in Figure 1, with the following values of the initial data, the mass m = 174 kg, moment of inertia along the lateral axis I= 35 kgm^2, the distance between the wheels l= 1430 mm, the values of mass center's coordinates *a, b, h*, were identified, and the elastic-damping characteristics of elastic suspension system and tires expressed with general marks, c_i, k_i,c_{ip},k_{ip}

i=1,2,...

Illustrative examples of the results of simulation studies are shown in Figure 4 to Figure 10. The results shown in Figure 4 to Figure 6 are related to simulation of motorcycle's vibrational process exposed to step excitation only of the front wheel. In accordance with these images the following characteristics of the process are emphasized. Vertically, z and angularly α, motion of supported mass, m, according to Figure 4a. and 4b., as the transient vibration damping processes are different during the flow and also according to the values of their natural frequencies, what could be concluded on the basis of their mutual coupling graphics, shown in Figure 5a. On the basis of these results the coordinates of the supported mass rotation center could be determined and its position relatively to the center of the total mass in relation to the positions of the driver's seat and rear passenger, as an important indicator of the impact of motorcycle's characteristics on vibrational loads of human factors.

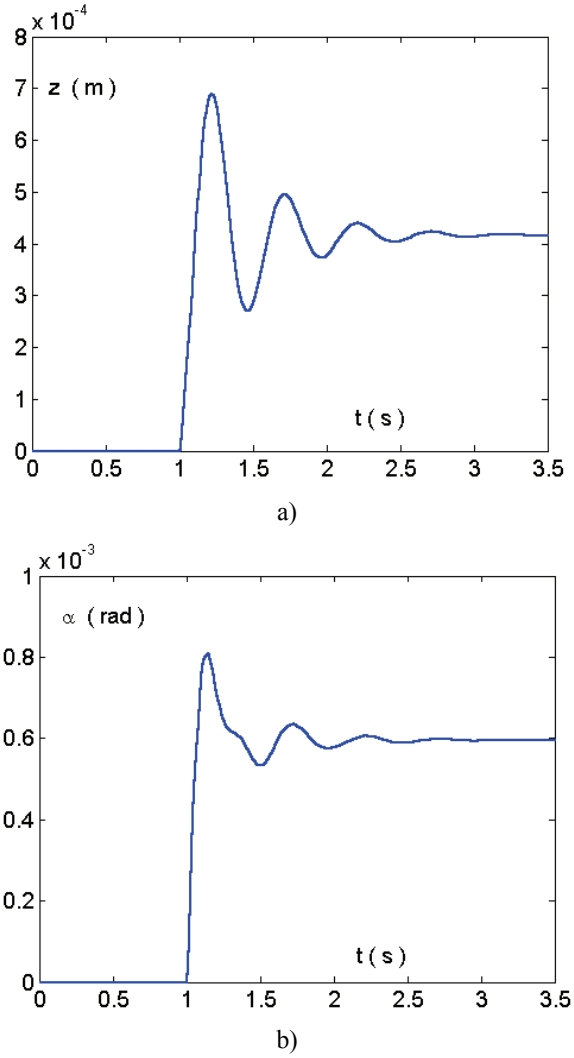
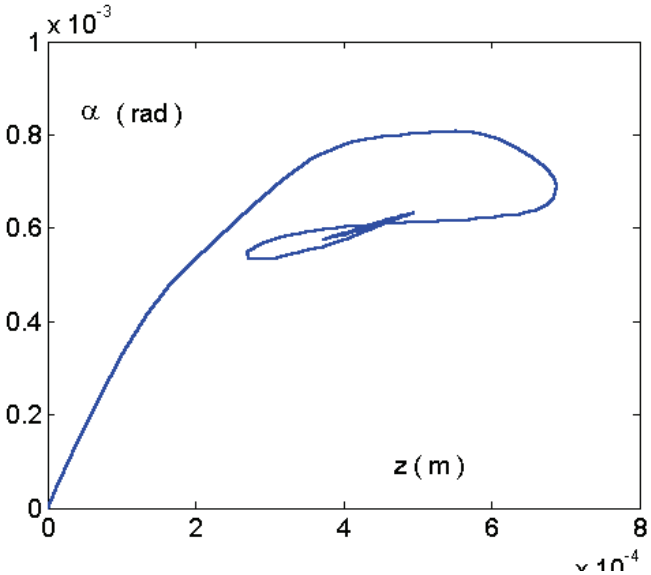
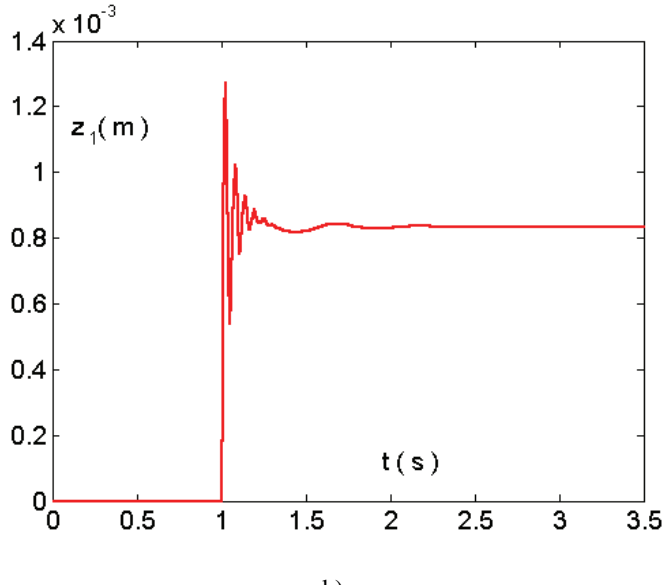


Figure. 4. a / *vertical*, **b** / *angular motion of motorcycle's sprung mass under step excitation along the front wheel*



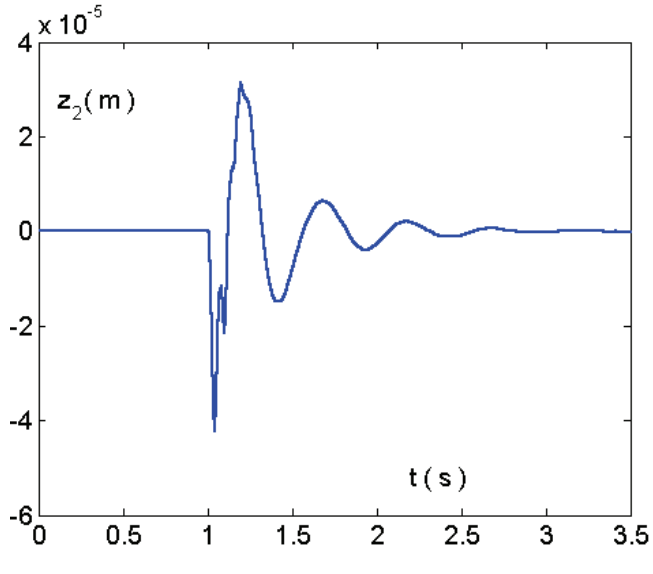
a)



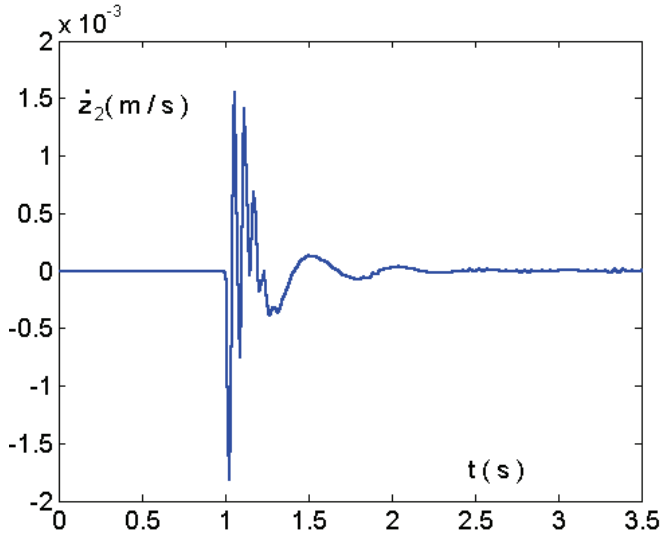
b)

Figure 5 a / *mutual coupling of vibrational process in Figure 4,* **b** / *vertical displacement of the center of non-supported mass of the front wheel for the above type of excitation*

Figure 5b, shows a characteristic superposition of low-frequency vibrations of the sprung mass and the high frequency of non-supported mass as result of front wheel vibration conditioned by a significant difference in the stiffness of elastic suspension and tires.



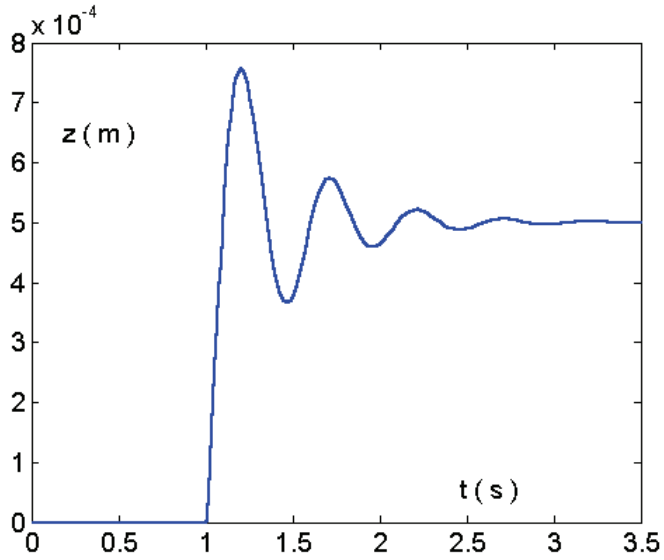
a)



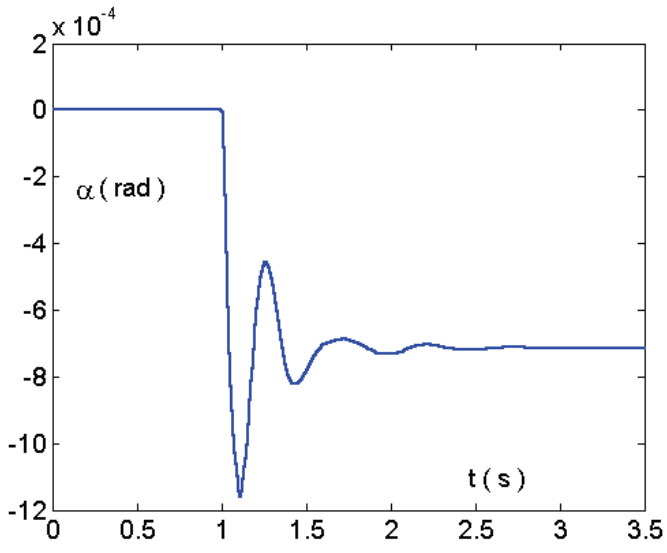
b)

Figure 6 a / **b** / *vertical displacement and the corresponding velocity of the center of non-supported mass of rear wheel, respectively, for given type of excitation*

Comparing the vibrational processes from Figure 5b and 6a, a significant difference has been emphasized in their flows, regarding the share of low-frequency and high-frequency components. The reasons for this are different directions and contours for excitation transfer in one case and in another case. Insight of high-frequency vibrations in the second case is more complete based on the vibration speeds flow, shown in Fig 6b. In this sense, higher time derivate of observed processes provide more information about their influence.



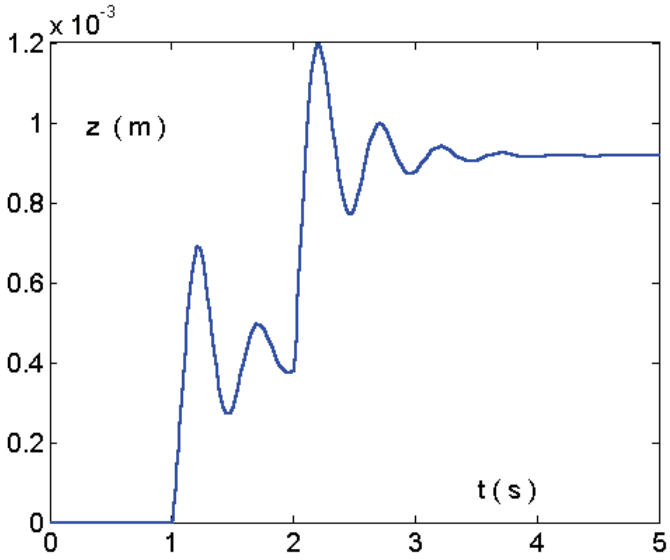
a)



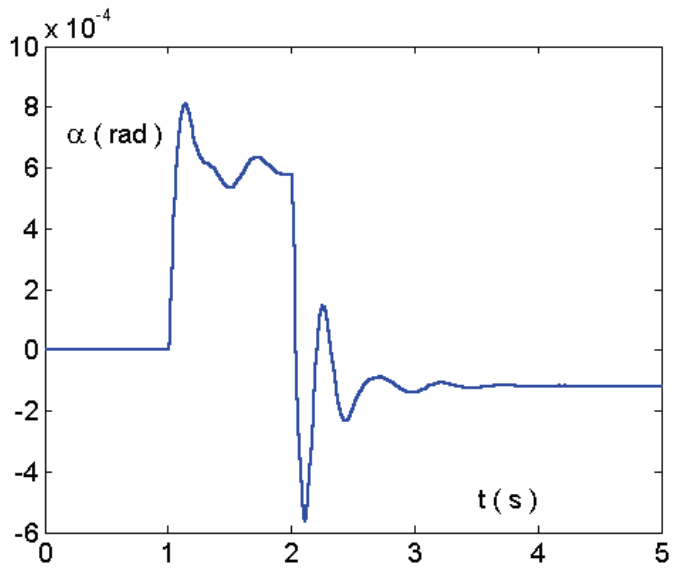
b)

Figure 7 a / *vertical*, **b** / *angular motion of sprung motorcycle's masses with step excitation along the rear wheel*

Typical examples of the vibrational processes while introducing step excitation over the rear motorcycle's wheel are given in Fig. 7a, b, for the vertical and angular motion of sprung motorcycle's masses. Compared to Figure 4a, b, higher levels of both transient processes are noticeable as same as the change of direction of angular movement, Fig. 7b.

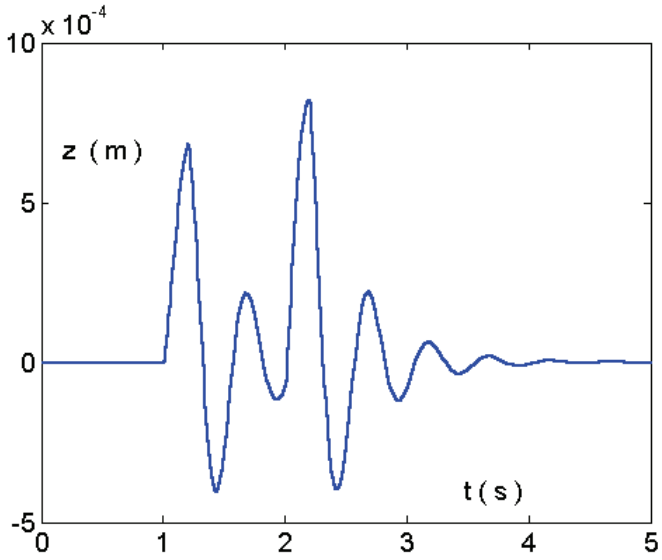


a)

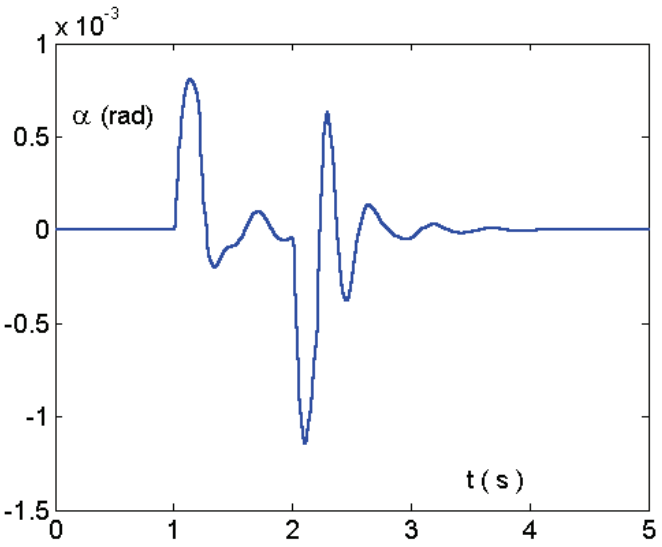


b)

Figure 8 a / *vertical*, **b** / *angular motion of sprung motorcycle's masses with step excitation along the both wheels*



a)

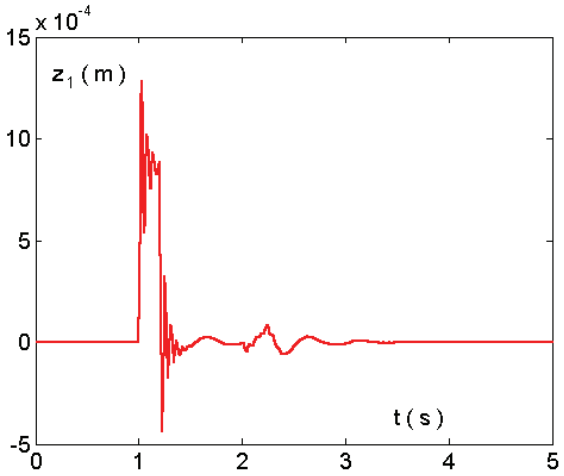


b)

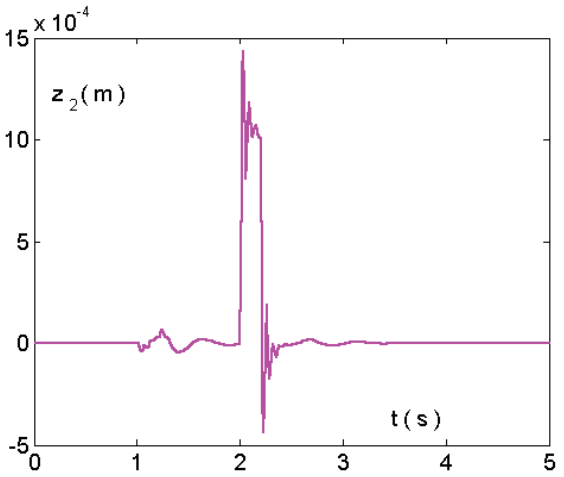
Figure 9 a / *vertical*, **b** / *angular motion of sprung motorcycle's masses with impulse excitation along the both wheels.*

In Figures 8. and 9. are shown typical examples of motorcycle's vibrational processes while introducing incentives to both wheels with adequate time delay depending on the values of the longitudinal velocity of movement and the distances among the wheels. In the first case for a step excitation, and in the second, for the impulse excitation. In accordance to diagram shown in Figure 9, also is provided an overview of vertical displacements of front and rear non-supported masses, in Figure 10.

On the basis of previously given illustrated overviews of simulated motorcycles vibrational processes, with short time excitation, can be outlined the relevant parameters for their evaluation in terms of the required performances. Generally speaking, they are parameters of evaluation of the development process; the levels, relations of superimposed components, harmonics, their frequency, nature and attenuation intensity. The final result of this set of estimation parameters is resumed to the parameters of their frequency content, expressed through the power of the process itself, in the time and frequency domains and in terms of comfort, stable and safe motion. In this sense, the compromise solutions are being seeking in the phases of design, construction, motorcycles usage, i.e. adjusting its constructive and exploitation characteristics, that means, the load mass distribution, tire selection, maintenance of the required technical conditions.



a)



b)

Figure 10a/b / *motorcycle's vertical displacement of non-supported mass, the front and rear respectively*

CONCLUSIONS

Single-trail vehicles are significantly present in off-road and road traffic and represent a major risk to the safety motion.

Compared to double-track trail vehicles these vehicles are difficult to control and manage because of the complex interactions with the environment and the driver, in order to maintain the stability of motion direction and position.

Their investigations are very complex, and modern simulation techniques in that sense are introducing some simplifications and reduce the costs.

Modeling and simulation of the basic motorcycle motion in vertical-longitudinal plane allows the observation of the influential factors on motorcycle vibrational processes in terms of comfort and safety of movement - and in that sense, finding a compromise solution between these requirements in respect of harmonizing structural and exploitation parameters. At the same time, these form an important base of information about the characteristics of vehicle behavior necessary for training of drivers in conditions where due to the energy crisis, ecological environmental requirements and other reasons, their usage is becoming more massive.

REFERENCES

[1] The Law about Safety Road Traffic, 5-to release "Službeni glasnik" Belgrade 2010.

[2] Rice, R., "Rider Skill Influences on Motorcycle Maneuvering," SAE *Technical Paper* 780312, 1978, *doi:10.4271/*780312

[3] R.S. Sharp and C.J. Alstead. The influence of *structural flexibilities on the straight-running stability of single-track vehicles. Vehicle System Dynamics, 9, 1980.*

[4] V.Cossalter, „Motorcycle dynamics", 2nd English edition, 2006.

[5] J. Stoffregen, „Motorradtechnik", durchgesehene und erweiterte Auflage September 2009.

[6] Radonjić, R., Janković, A., Aleksandrović, B. *(2010) The* study of the single track vehicles *dynamics. Mobility and* Vehicle *Mechanics, vol. 36, br. 3, str. 21-33*

[7] R. Radonjić, A. Janković, B. Aleksandrović, D. Radonjić, „Modeling of driver behavior", International Congres Motor Vehicles & Motores 2012 kongres MVM 2012, Kragujevac

[8] Aleksandrović, B., Đapan, M., Radonjić, R., Janković, A., "*Researching the correlations of motorcycle's vibrational processes in non-stationary motion regimes*", 10th International Conference of Electrical Engineering, Mechanical Engineering and Computer Science Achievements "DEMI 2011", Banja Luka, 2011, 26-28 May, ISBN 978-99938-39-23-1;



University of Nis
Faculty of Occupational Safety

„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

EXCITATING VEHICLE'S VIBRATIONS FROM THE ROAD SURFACE

Rajko Radonjic[1], Aleksandra Jankovic[1], Branislav Aleksandrovic[1], Dragoljub Radonjić[1]

[1] Faculty of Engineering, University of Kragujevac, Serbia, rradonjic@kg.ac.rs

Abstract - *The paper highlighted the significance of recording the characteristics of road surface roughness in order to determinate vehicle's vibration excitation, both for double-track, and single-track vehicles. Some researching methods and systems which were implemented on trailers are presented here, then on passenger car and also on motorcycle. A special algorithm is formed to determinate characteristics of rough roadway, based on measured vertical accelerations at the wheel centres of examined vehicles. Illustrative examples of researching are shown, and it is emphasized how important the application of those results is, not only for investigation and simulation of operating regimes of the vehicles, but also for estimation of roadway quality and roadway categorization.*

1. INTRODUCTION

The road surface roughness cause the oscillatory processes of motor vehicles. The intensity of this processes depends on the structural parameters of the vehicle, a regime of movement and characteristics of the road surface roughness, and affect on the safety developments, passenger comfort, working lifetime of the elements and assemblies of vehicles, level of road damage. Ordinate of road surface roughness are random functions of distance or time. In order to presentation them, the statistical features in time domain and frequency domain are used. For these reasons, recording of the heights of road surface roughness and processing of obtained results is a complex measuring and numerical problem. In the most cases, in order to form the description of the road surface, a certain number of already measured roughness heights along longitudinal sections is used, along the profile.

Depending on the purpose of the results, different methods and measuring devices are used. From the aspect of roadway quality control during the phases of road construction, their usage and their maintenance, a different types of the plan-graphs were used, [1], [2]. Their common feature is the ability to make the records "point by point", at lower working speeds, that means, it is the function of the length of measured sections. The obtained results represent the baseline characteristics of roadways, relevant for the estimation of its quality. Sufficiently high operating speed recording of the road roughness features, and the processing of obtained results, can be achieved only by using the measurement principle of electrical and electronic measuring devices. Measuring and technical side of the problem contains two partial tasks: 1) adequate view of parameters of the roughness (amplitude, velocity, acceleration), analogue electrical values, 2) selection of domains for data processing (time, frequency). This second group of methods can be further classified into direct and indirect methods of roughness parameter measuring, [3], [4], [5].

In terms of the measuring range of used equipment, the following remarks one should bare in the mind: in order to research vehicle's oscillation it is sufficient to consider the field of excitation with frequencies from 0.5 to 20 Hz. The scope of vehicle's speed changes is 5-50 m/s, a measuring scope of roughness wavelength is defined from 0.25 to 100 m.

2. SELF EXPERIANCE

Within R&D tasks and in cooperation with the Institute for Automobiles, Zastava Automobili, the problem of the measurement of road roughness has been present at the Faculty of Engineering Science nearly for four decades, [3], [6]. In this sense, the appropriate methods and measuring devices for dynamic recording of roadway excitation effects [7] were developed or vehicle's response on this effect [8]. One of the examples is the measuring trailer with measuring device Fig. 1, whose construction has been developed and implemented at the Faculty of Engineering Science, Kragujevac.

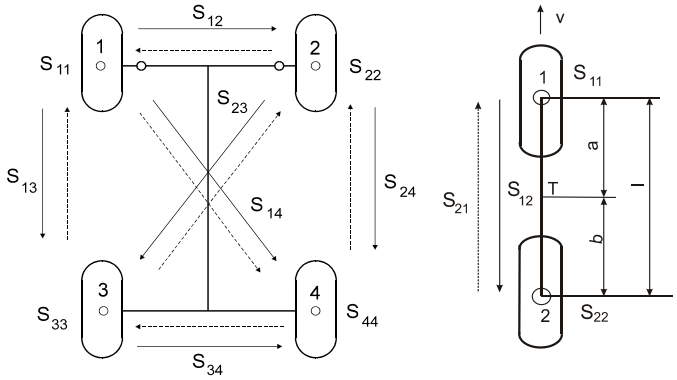


Fig. 1 *Examined vehicle with a trailer and a measuring device for road roughness recording*

The basic technical characteristics are: the distance between the axis of measuring trailer and drawing vehicle is 3 m, the length of measuring device, mounted underneath the trailer is 1.2 m, the frequency of the measuring device is 31 Hz. Apart of this method, for roughness recording and apart of database system creation for representative local roads, by time, there was a need, to record the roadways in real time in order to define the specific kinds of excitation of both, double-track vehicles and their coupled vehicles (trailers) and single-track vehicles, motorcycles and bicycles. Description of the measurement principles and equipment that was used, as well as an illustration of the results of this research are presented in the following sections of this paper.

2.1 Teoretical base

Roughness of the road effect on double-track vehicles, by means of four wheels, as four point inputs in the dynamic system, as it is shown in Fig. 2.a while the single-track vehicle with two wheels effect as 2 point inputs of dynamic systems, according to Fig. 2b.



a) double track vehicle b) single track vehicle

Fig. 2 *Models of roughness excitation effects for a) double-track, and b) single-track vehicle*

Observed in the frequency domain, at any point of the system, the scope of vehicle's response to roughness excitationis defined:

$$S_{kk}(f) = \sum_{i=1}^{4}\sum_{j=1}^{4} H_i^*(f)H_j(f)S_{ij}(f) \tag{1}$$

With the following marks, $H_{i(f)}$, $H_{j(f)}$ - are marked, partial transfer characteristics, $S_{ij(f)}$ - cross and auto spectra power fordefined inputs. The base characteristics of excitation in these expressions are auto spectrum $S_{ii(f)}$, i=1,2,3,4 in the following text marked as power spectrum. By means of power spectrum, characteristic coupling and excitation modes can be obtained, as it is indicated in Fig. 2a and 2b.

Power spectrum of one wheel excitation, $S_z(f)= S_{ii}(f)$, the height of the roughness, roadway profile length z(t), can be determined in one of the following ways, [9]

$$S_z(f) = \lim_{\square}\frac{1}{T}|a_T(f)|^2 \ , T \to \infty \tag{2}$$

$$a_T = \frac{1}{\sqrt{2\pi}}\int z(t)e^{-j2\pi ft}dt \tag{3}$$

where $a_T(f)$, is the spectrum of the complex amplitude. Spectrum density $S_z(f)$, is associated with total time power z(t), with the expression:

$$[z^2(t)] = \lim_{\square}\frac{1}{2T}\int_{-T}^{+T} z^2(t)dt = \int_0^{\infty} S_z(f)df\,, \qquad T \to \infty \tag{4}$$

Expression (4), shows how the overall power of the random process z(t),is distributed in the observed frequency domain

Derivating this expression the following expression is obtained:

$$S_z(f) = \frac{d[z^2(t,f)]}{df} = \lim_{\square}\frac{\Delta z^2(t,f,\Delta f)}{\Delta f} \ , T \to \infty, \Delta f \to 0 \tag{5}$$

Finally, the power spectrum of roughness can be expressed through the corresponding autocorrelation functions:

$$S_z(f) = \frac{1}{\pi}\int R_z(\tau)e^{-j2\pi f\tau}d\tau \tag{6}$$

Therefore the expressions (2), (5) and (6), represent three practical procedures for determination of roughness power spectrum in the following way:

a) by means of the fast Fourier transform algorithm

b) by means of selective measurement of forces in the infinitely small frequency ranges

c) by means of Fourier transformation of a predetermined autocorrelation function $R_z(\tau)$, respectively.

Among the car's speed v, the wavelength roughness λ, circular ω and temporal frequency f, there is the following relation:

$$v = \lambda f = \frac{1}{2\pi}\lambda\omega \tag{7}$$

Between the wavelength λ, and wave roughness frequency Ω there is a relation:

$$\Omega = \frac{2\pi}{\lambda} \tag{8}$$

From equations (7) and (8), the power spectrum of road roughness height (2), (5), (6), a part of the argument f can be

also expressed in the function of one of the following arguments ω, λ, Ω, which were shown above,

Besides the power spectrum height of road roughness S_z (f), the excitation of the vehicle can be expressed as the spectrum of the first and second derivation of the function of roughness power spectrum, i.e. roughness velocity and acceleration, $S_{z'}(f)$, $S_{z''}$ (f), respectively. In accordance with (5), these terms can be formed in the following way:

$$S_{\ddot{z}}(f) = \frac{d[\ddot{z}^2(t,f)]}{df} \quad (9)$$

$$S_{\ddot{z}}(f) = \frac{d[\ddot{z}^2(t,\Omega)]}{df} \quad (10)$$

On the basis of expressions (7) and (8), are obtained different types of vehicle's excitation spectrum from the roadway:

$$S_z(\omega) = \frac{1}{v} S_z(\Omega) = S_z(\lambda)(-2\pi v)\omega^{-2} \quad (11)$$

$$S_{\ddot{z}}(f) = S_z(\lambda)4\pi^2 v \quad (12)$$

$$S_{\ddot{z}}(f) = S_z(\lambda)16\pi^4 v f^2 \quad (13)$$

$$S_z(\Omega) = S_{\ddot{z}}(f)\frac{v}{32\pi^5 f^4} \quad (14)$$

2.2 The Measurement System

The measurement system has been realized based on "1/4" model vehicle's oscillatory systems, Figure 3. Generally the amount of roughness of the roadway's longitudinal profile is shown relatively to the reference plane "RR" in a function, of the distance z(x), or a time z(t). Measuring - technical problem of defining the reference plane is solved, in this case, by using acceleration sensor, with reference seismic mass. Inductive sensors of vertical acceleration is set at the centre of the wheel, with coordinates marked with s- location of the centre of the wheel, and the sensor housing, y - position of sensor's referent mass, r - measuring value, z_H - a position of vehicle's supported mass, c_o, k_o, c_{pi}, k_{pi} , c_d, k_d, stiffness and damping of the suspension systems, tires, sensor's reference mass, respectively.

As the result of recorded wheel's centre vertical accelerations s'' (t), by determination of the power spectrum by means of using of mathematical model (14), one can obtain the power spectrum of wheel's center movement:

$$S_s(\Omega) = S_{\ddot{s}}(f)\frac{v}{32\pi^5 f^4} \quad (15)$$

Which also represents the equivalent vehicle's excitation from the road surface reduced in the wheel's center. For the determination of indirect excitation of roughness in contact between tire and road, it is necessary to identify the transfer characteristics of tires:

$$H_{\ddot{s}\ddot{z}}(f) = \frac{S_{\ddot{s}\ddot{z}}(f)}{S_{\ddot{z}\ddot{z}}(f)} \quad (16)$$

and then, on the basis of (15) and (16) to determinate excitation spectrum of the road in the contact surface

$$S_z(\Omega) = S_s(\Omega)|H_{\ddot{s}\ddot{z}}(f)|^{-2} \quad (17)$$

where: H_{SZ} (f) – is a transfer function of wheel's center channel acceleration and acceleration of the contact surface, $S_{SZ}(f)$, $S_{ZZ}(f)$, the corresponding cross and auto spectrum, respectively.

Transfer characteristic of the tire according to the algorithm (16) was identified as the part of an experimental vehicle on testing laboratory installation with oscillating plates.

Recording of vertical accelerations in the wheel's centre in the previous period were performed at two mobile systems - passenger car, such are double-track vehicles, a detail of the sensor is shown in Fig. 4a and motorcycles, as single-track vehicle, a detail of its sensor is shown in Fig. 5a, b, for the front and the rear wheels, respectively.

Details about installation of vertical acceleration sensor at the center of the rear wheel on passenger car is shown in Fig. 4a, and at the centers of the front and the rear wheel of motorcycle in Fig. 5a and 5b for the front and rear wheels respectively.

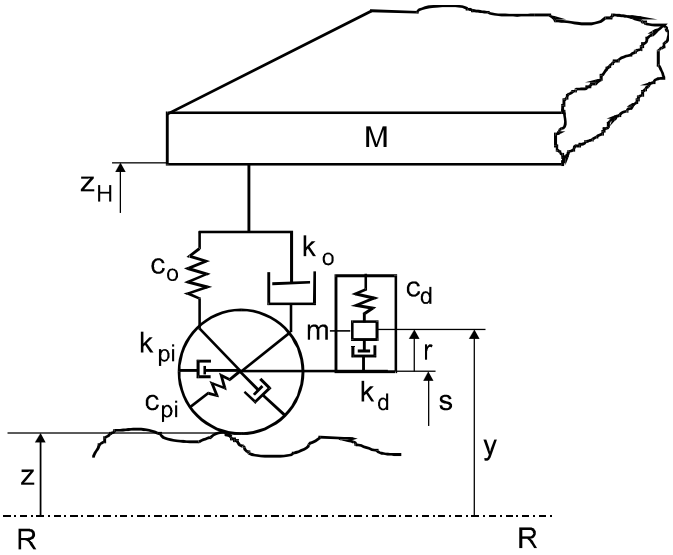
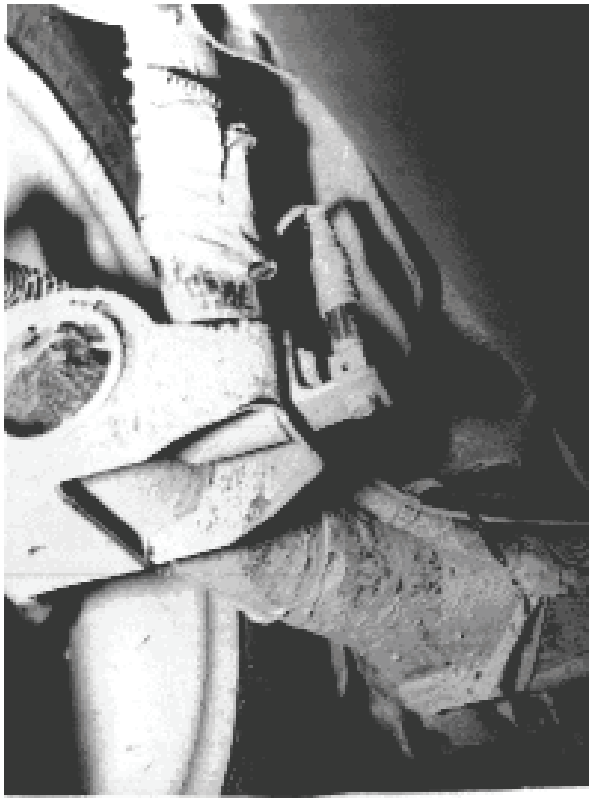


Fig. 3 *"¼".Model of vehicle's vibratory system and sensor of wheel's center acceleration*



a)



b)

Fig. 4 *a) detail of the sensor in wheel's center of passengers car; b) SPIDER 8 measuring system on a motorcycle*



a)



b)

Fig. 5 *Acceleration sensors in the motorcycle wheel's center a) front, b) rear*

The results of identification of wheel's transfer characteristics, obtained on a laboratory device, are shown in Figure 6. Based on the flow of amplitude-frequency characteristics of $H_{sz}(f)$, a self-frequency of wheel-tire assembly is registered, in the scope of 10 Hz. Below this frequency the amplitude-frequency characteristics flow is deposited with gain 1, which is suitable for the conversion of excitation both, in the wheel's periphery and in its center.

The records of vertical acceleration of vehicles wheel's centers on an asphalt road, at the speed of 14 m/s, are shown in Fig. 7. Based on this, one can observe the random process flows and the time delay of rear wheels excitation. On the basis of these records and the algorithms of the mathematical models (2) and (15), the power spectrum of wheel's center shifting for the two limiting speeds 10 m/s, 30 m/s and for asphalt road are determinate. The results are presented in double log. overview in Fig. 8. On the same figure is also shown the mathematical formulation of the identified power spectrum in the form:

$$S_z(\Omega) = S_z(\Omega_0)\left[\frac{\Omega}{\Omega_0}\right]^{-W} \tag{18}$$

The expression (18) defines the characteristic equation of the line with specific parameters $S_z(\Omega_o)$, Ω_o,W, which is in accordance with the results [10], [8]. Narrow scope, which is defined by limited speeds of 10 m/s and 30 m/s, at Figure 8, represents the invariance of the basic characteristics of road roughness with the respect to the recording speed variation. On the other hand rectilinear flow of identified characteristics in Fig. 8, in accordance with the identified transfer characteristics of the tire in Fig. 6, allows extrapolation of obtained results of power spectrum in frequency domain above self-frequency of tire-wheel assembly. In this way, the proposed method allows indirect determination of excitation roughness's power spectrum in contact between pneumatic and roadway, in the overall frequency domain which is of the great importance for vehicle's oscillatory processes studies.

The parameters of identified road roughness power spectrums, $S_z(\Omega_o)$ and W, are also suitable evaluation criteria for road excitation effect on a vehicle, and basic classification of the roads from the aspect of quality, as well as, taking into the consideration the situation and the need for repairs and maintenance. In order to illustrate these possibilities, identified power spectrum were compared, according to the proposed methodology, four roads in different types of roadways, in Fig. 9 as follows: asphalt, paving, concrete and macadam. From the mathematical point of view, description parameter $S_z(\Omega_o)$, defines the height of the lines from Fig. 9, and the parameter W, represents their inclination. From the viewpoint of road roughness physical description, the first is related to the height of roughness and the other is related to the wavelength, this is an indicator of road waviness. In the latter example in Fig. 9, the scope of the first parameter changes is 1÷15, while for another is 1÷1.3. Thus, the first parameter, $S_z(\Omega_o)$ is more selective in terms of quality estimation, roads state and road categorization, therefore it could be the basis for analysis and standardization of this kind.

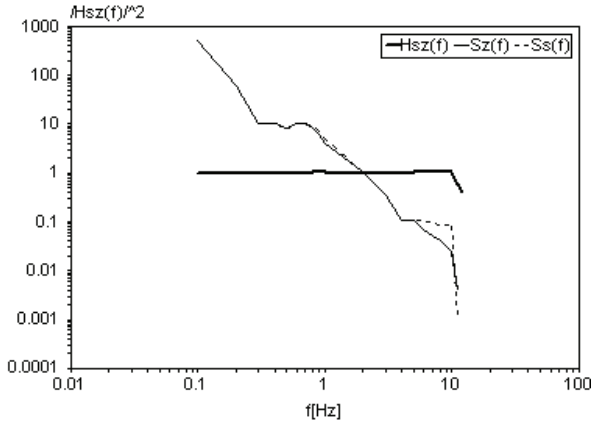
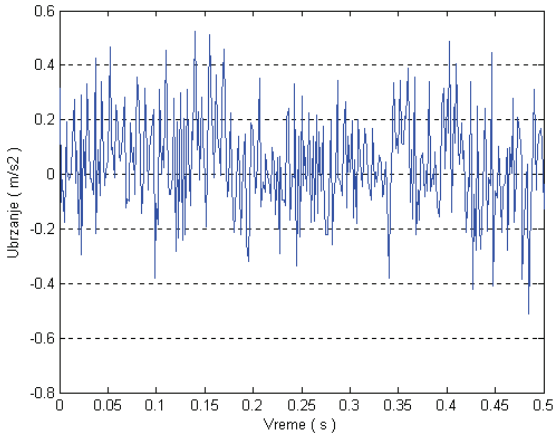
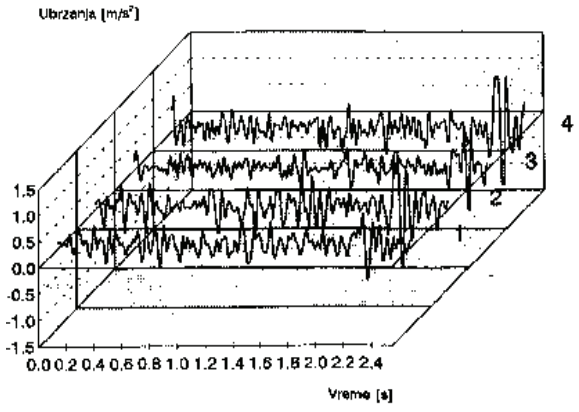


Fig. 6 *Transfer characteristics of the tire*



a)



b)

Fig. 7 *Time records of vertical accelerations in the wheel's center, a) rear wheel of motorcycle, b) all four-wheel of the car*

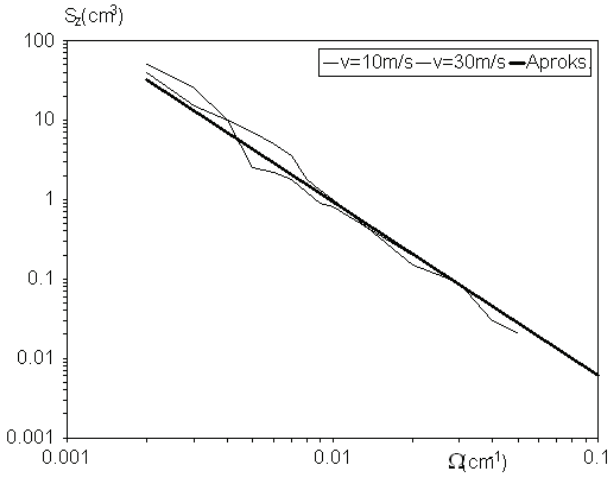


Fig. 8 *Excitation spectrum of road roughness*

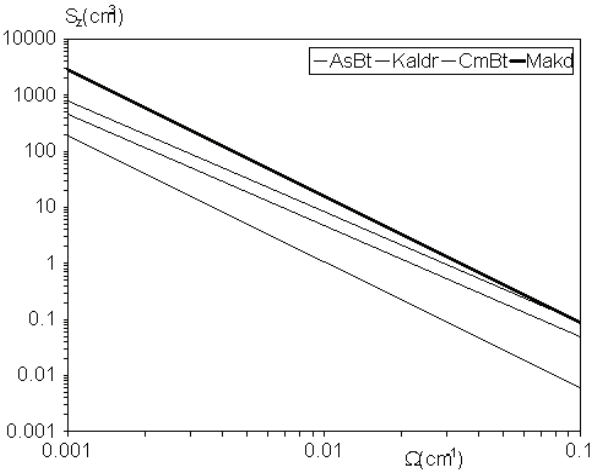


Fig. 9 *Comparison of power spectrum for different types of roadways*

3. CONCLUSION

The proposed dynamic method for indirect recording of vehicle's excitation from roadway roughness, allows conducting of experiments with wide scale variation of operating speeds. Vertical acceleration sensors were placed at the centers of the wheels and by measured records processing, one can identify excitation in contact zone between tire and roadway. Individual parameters of the spectral characteristics are the basis for roadway quality evaluation and their categorization.

REFERENCES

[1] H. Kohler, G. Beltz: Die Ebenheit von Strassen und ihre Kontrolle mit dem Ebenheitsprufgerat Planograf. Strasse und Autobahn, vol.11, No8, 1960.,pp 47-53.

[2] U. Gerz, L.Ohnemuller: Entwicklung und Erprobung eines Messgerates zur Aufnahme von Strassenquerprofilen. Strasse und Autobahn, Vol.36, No9, 1985.,pp 25-31.

[3] D. Simić, Lj. Jelić, R. Radonjić: Ispitivanje i klasifikacija puteva sa obzirom na neravnine podužnog profila Laboratorija za motorna vozila i motore, Mašinski fakultet Kragujevac, 1973., s.1-81.

[4] H. Braun, U. Gerz, P. Sulten: Sammlung und Auswertung von Strassenunebenheitsdaten. Untersuchung und Vergleichverschiedener Messgerate und Auswertverfahren. IfF-Berichte, No651, 1985. Braunschweig.

[5] T. Mimuro, T. Meamura: Road profile measuring system using laser displacecement sensors. JSAE Review, Vol.11, No4,1990, pp76-81.

[6] D. Simić, R. Radonjić: Matematičke osnove za opis karakteristika neravnina puta. Motorna vozila Motori br.2, 1975, s.63-93

[7] R. Radonjić, A. Dunkić: Definisanje pobude vozila od neravnina puta. Motorna vozila Motori br.68/69, 1986, s.153-166.

[8] R. Radonjić: Identifikacija dinamičkih karakteristika motornih vozila, Monografija, 1995, Mašinski fakultet Kragujevac.

[9] J. Bendat, A.Piersol: Random data. Analysis and Measurement Procedures. John Wiley & Sons,1986.

[10] J. Dodds, D. Robson: The description of road surface roughness. Journal of Sound and Vibration. Vol.31, No, 1975.,pp.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

ROLLER ELEMENTS BEARING VIBRODIAGNOSTICS

Ninoslav Zuber[1]

[1] Faculty of Technical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, Novi Sad, email: zuber@uns.ac.rs

Abstract – *This paper addresses a review of existing roller element bearing's defects generation and their development during the bearing operation. A brief review of existing universal vibration signals processing methods for bearing's defect monitoring and analysis in time and frequency domain is presented.*

1. INTRODUCTION

Roller elements bearings are the most common parts in rotating machines and unjustifiably they are claimed to be the elements that are most responsible for machine's unplanned stoppages and wrecks. Also, at the same time unjustifiably, vibrodiagnostical methods are mostly understood as the methods for bearings state monitoring and analysis, despite the fact that bearings are just one part of the rotating machine that could cause high vibrations. Unplanned stops and incidental damages directly leads to loss of production, high maintenance costs and sometimes to fatal losses of human lives too. Therefore and also taking into account that only 10% of all bearings will work during their projected life cycle, development of special vibrodiagnostical methods and methods of signal processing, together with the analysis of their applicability in roller element bearing diagnostics is very important.

2. EXPERIMENTAL SETUP

Experimental part of the work described in this paper is done on a specially designed test rig shown on figure 1. Test rig is consisted of one AC motor 0.37 kW, which is over an elastic coupling connected to the rotor with two rotating discs where unbalanced masses can be mounted. Rotor is supported by two UC201 roller elements bearings. Four IEPE accelerometers type AC201-1A (manufacturer: CTC, USA) are mounted in horizontal and vertical radial directions on the bearing housings with mounting studs. For speed measurement a non-contact laser sensor (manufacturer: Monarch instruments, USA) is used with a reflecting tape mounted on rotating discs.

For simultaneous multichannel data acquisition a 16 channel acquisition system OneproD MVX with a corresponding software for measurement setup and analysis OneproD XPR300 (manufacturer: 01dB-Metravib, France) is used. Besides mechanical vibrations a noise measurement is also performed using a portable sound analyzer Blue Solo with a corresponding software dbTrait (manufacturer: 01dB-Metravib, France).

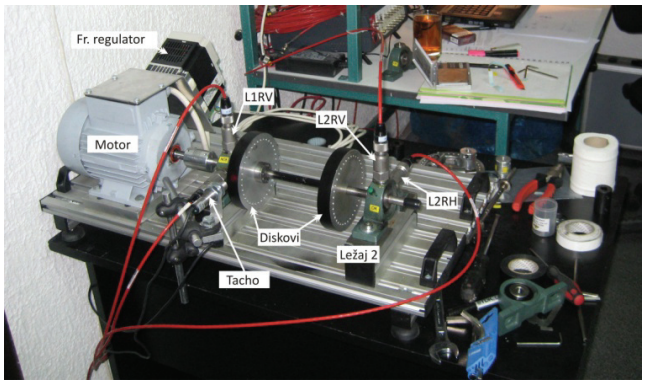


Fig. 1. *Test rig used for data acquisition*

For the experimental purposes, several damages on roller element bearings are introduced: bearing in healthy condition (label "OK"), bearing with a defect on the outer race out of the loading zone (label "OU"), bearing with a defect on the outer race in the loading zone (label "OL"), bearing with small defect on the inner race (label "I"), bearing with a larger defect on the inner race (label "II"), bearing with small looseness (label "Z1"), bearing with large looseness (label "Z3"). All measurements are acquired at 22 Hz speed of the drive. Using well known formulae and bearing's dimension data, bearing defect frequencies in terms of rotating order are: BPFI[1] = 4.9, BPFO[2] = 3.1, BS[3] = 2.1, FT[4] = 0.39.



Fig. 2. *Bearings used in test, defect on outer (left) and outer (right) race*

3. METHODS FOR IDENTIFICATION AND MONITORING OF BEARING DEFECTS

Today we can use several nondestructive testing methods for evaluation of roller elements bearings state:

[1] *Ball pass inner race*
[2] *Ball pass outer race*
[3] *Ball spin frequency*
[4] *Fundamental train – cage frequency*

1. **Vibration measurement and analysis** is a well-known and proven method for identification of damages in roller elements bearings. Under the assumptions that we use an appropriate transducer (accelerometer with appropriate amplitude and frequency range), that the mounting method used is good enough to adequately transfer the vibration signals from bearing's housing to transducer and that that appropriate methods of signal analysis is used, vibration signal contains all the necessary information required for reliable identification of bearing defect.

2. **Noise measurement**. In the early stages of defect development, roller elements bearing are generating acoustic waves at high frequencies that human ear cannot detect. Methods of acoustic emission measurement and analysis are very useful and efficient in detection of defects in bearings at early stages. In later stages, it is possible to use traditional noise measurements in the form of equivalent noise level measurements.

3. **Measurement of bearing temperatures** – either direct temperature measurements (for example with thermocouples or pyrometers) or temperature field visualization using infrared imaging devices. Very often and especially in the cases where bearing has a distributed defect a high bearing housing temperature is present.

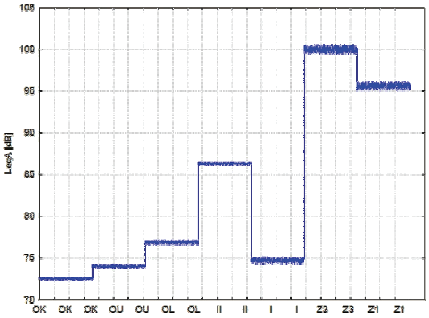


Fig. 3. *Sound pressure levels for different bearing faults*

4. **Oil analysis** and particle counting is very useful for identification of defects in later stages of development.

4. MECHANISMS OF DEFECTS GENERATION IN BEARINGS

Premature defects in roller elements bearings can be occur due to many factors where the most commons are: fatigue crack, wearing, plastic deformation under the components of the bearing, corrosion, brinelling, bad lubrication, improper mounting methods, inadequate bearing choice etc. Very often, the mentioned mechanisms are overlapped and it is very common that one mechanism excites other mechanisms, which leads to total failure of a bearing.

1. **Fatigue crack.** Bearing that is subjected to designed dynamic load will fail under the mechanism of fatigue crack after the projected life cycle is reached. Fatigue crack begins with occurence of microcrack just bellow the inner bearing race. Due to the bearing load this crack propagates toward the inner race surface and causes the material ablation. If such a damaged bearing is left in operation due to higher stresses in the zone of a crack, the crack expands and the material ablation is intensive. This way a defective race leads to a disturbation in roller elements motion over the crack which results in occurence of periodic impulses in vibration signal. If such a damaged bearing is still left in operation the distrurbations are so intensive that the generated impulses can excite natural frequencies of the bearing's housing. Next stage of defect development results in defects geeration on other elements of the bearing (rollers, other race and the cage). At the end such an operation leads to developed loosenes in the bearing and its total failure.

2. **Wear** is another mechanism for defect occurence. Most often it develops as a results of presence of particles inside the bearing due to improper sealing or due to the paricle contaminated lubricant. Intensive wear leads to distrurbation of internal geometry of the bearing's elements and this results in development of loosenes inside the bearing. In this condition besides the rolling motion of the roller elements a sliding is present also, and this can lead to bearing failure. Depends on which bearing elements are worn, the frequency spectra content can differ from case to case. If the inner and outer race geometry is disturbed due to the wear, frequency spectra will typicaly contain rich family of harmonics, which is a common situation in the case of presence of periodic and non periodic impacts in time waveform. Also frequency spectra could be risen due to the presence of a broadband noise. If the geometry of the roller elements is disturbed then a frequency spectra can contain sidebands due to the amplitude modulation.

3. **Plastic deformation** on the contact surfaces develops as a results of the bearing overloading and can be seen as indentations on the bearing races.

4. **Corrosion** in bearing develops due to the presence of water or acids that contaminate the bearing lubricant. This is a common situation with damaged seals or as a result of condensation due to the rapid cooling. Corrosion is manifested as a rust on the bearing's races and results in very unevenly operation of bearing followed by high noise coming from the bearing. Rust contaminates the lubricant and this results to development of wear inside the bearing.

5. **Brinelling** is a type of defects which is manifested with a large number of equidistantly spaced indentations on the bearing's race and can develop due to: static overloading which results in plastic deformations, due to constant exposing of stationary part of the bearing to the vibrations that come from the neighboring machines (it is not uncommon to have a failure of the pump with zero hours of operation which is nect to the pump with high levels of vibration) and due to the electric discharge that goes through the bering. In any of the described scenarios bearing will have equdistantly spaced indentations which result in very noisy operation.

6. **Improper lubrication** is a very common cause of premature bearing failures. If an inadequate lubricant is selected or if the bearing is left without a lubricant the result will be raising of temperature due to the direct contact of bearing's elements - contacts are in the form of microwelds that develops immeadiately. There are three critical places in the bearings: contact race-roller, roller-cage and cage-race.

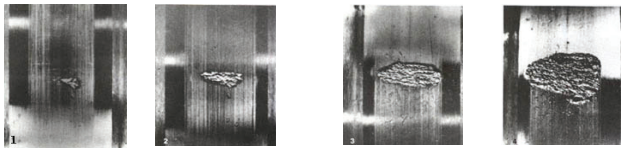


Fig. 4. *Development of a fatigue crack on the inner race*

7. **Improper mounting** leads to the bearing overloading in radial and axial directions which results in generation of misaligment condition . This results in a very noisy operation and in the difference between the temperatures on both races. Due to that there is a presence of high contact stresses which result in development of fatigue crack. Due to the overloading a bearing lifetime is dramaticaly reduced. The L_{10} time (lifecycle for the 90% of the beraings inside the family under the test) is defined as :`

$$L_{10} \approx \frac{1}{\Delta RPM} \times \left[\frac{1}{\Delta LOAD}\right]^3 \quad (1)$$

Where the ΔRPM is the speed change, while the ΔLOAD is the dynamic change of bearing loading.

Symptoms that develop inside the damaged bearing are very compex and sometimes they can't be easyly seen. Apart from the localised defects, such as indentations on races and rollers, distributed defects ask for application of the most advance signal processing methods. Also a scientific and engineering chalenge is the rapid change of vibrations signals coupled with the development of a defect. Every new indentation, for example on a bearing race, will generate a pulse train in the timewave. As the borders of the

5. METHODS OF VIBRATION ANALYSIS FOR IDENTIFICATION OF BEARING FAILURES

Everytime when a roller element passes over the indentation on a race a decrease of internal strain will be produced, while when a roller element passes over the metal particle that is on the race due to the flaking of the components there will be an increase of bearing's internal stresses. This transient forces result in rapid change of accelerations of bearing's components.

The most used methods of vibration signals analysis applied to identification of defected bearings are:

1. Time waveform analysis
2. Analysis in the frequency domain.
3. Techniques of spectral enveloping and demodulation.
4. Time-frequency transformations.

Techniques of time waveform analysis are focused on extraction of statistical parameters of raw or filtered time waveform signals in order to quantify the transient phenomena, which is present in case of defective bearings. The most common parameters are: *Root mean square* - RMS, *peak value*, standard deviation – StDev, peak factor – PF, Kurtosis parameter – *Kurt* and *defect factor* – *DEF*. These parameters are defined as:

$$P = \frac{1}{2}(\max(x(t)) - \min(x(t))) \quad (2)$$

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x(i))^2} \quad (3)$$

$$StDev = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x(i)-\bar{x})^2} \quad (4)$$

$$PF = \frac{PP}{RMS} \quad (5)$$

$$Kurt = \frac{\frac{1}{N}\sum_{i=1}^{N}(x(i)-\bar{x})^4}{StDev} \quad (6)$$

$$Def = a\,P + b\,RMS \quad (7)$$

where x(i) is the i-th digitized amplitude in vibration signal with total of N samples. $\bar{x}$ is the average value.

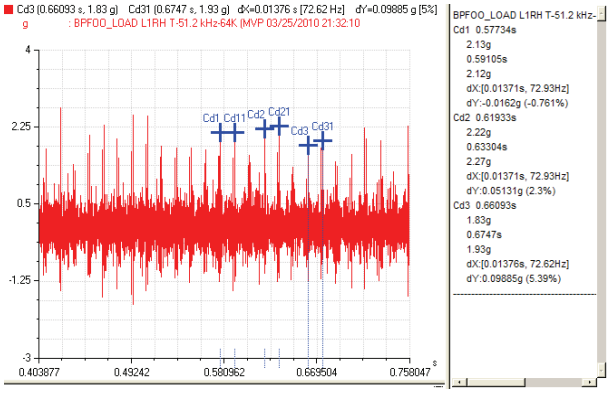


Fig. 5. *Time waveform of the bearing with a defect on the outer race – record from the test rig*

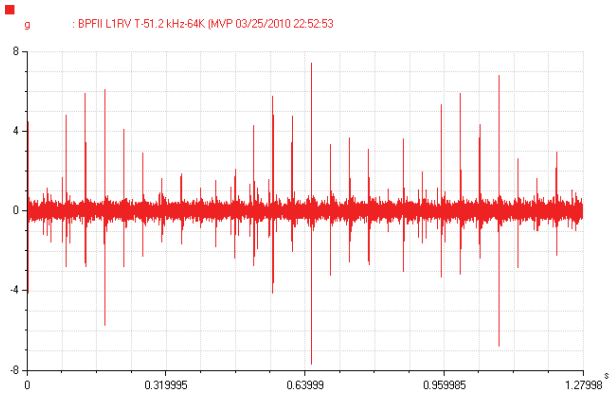


Fig. 6. *Time waveform of the bearing with a defect on the inner race – record from the test rig*

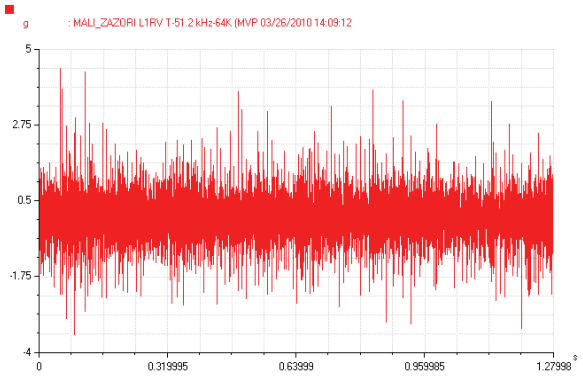


Fig. 7. *Time waveform of the bearing with small looseness – record from the test rig*

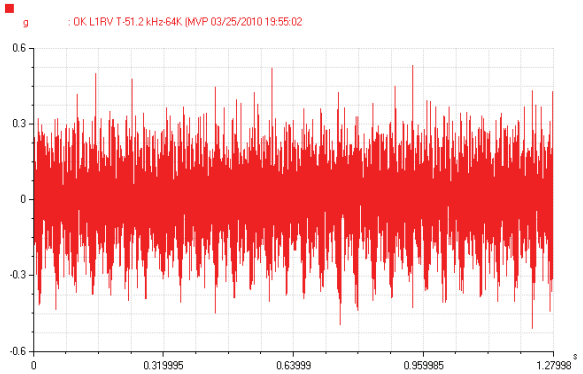


Fig. 8. *Time waveform of the bearing without any defect – record from the test rig*

Analysis in the frequency domain is based on representing the vibration signals in frequency domain using the well-known algorithm of fast Fourier transformation – FFT. The main advantage of analysis of signals in frequency domain is identification of periodicity in time domain and decomposition to discrete frequency components that cannot be easily seen in the raw time waveform. Thanks to this, the spectral analysis is the most used analysis method in vibrodiagnostics. Also using methods of automated extraction of spectral components or frequency bands in the form of scalar parameters, spectral analysis can be used for monitoring of defect development and bearing life prognostic.

On the figures bellow, frequency spectra recorded from the mentioned test rig are presented. The basic step in spectral analysis is knowledge of system's forcing frequencies, which are calculated on the base of kinematic data (speed, transmission ratio, number of gears, blades, vanes, type of bearings etc.). On the frequency spectra shown below a defective bearing frequencies are marked as: C1 is a cage frequency, B1 is a ball spin frequency, E1 is the ball pass frequency at the outer race and i I1 is the ball pass frequency at the inner race. f_o marker is the position of the drive's speed.

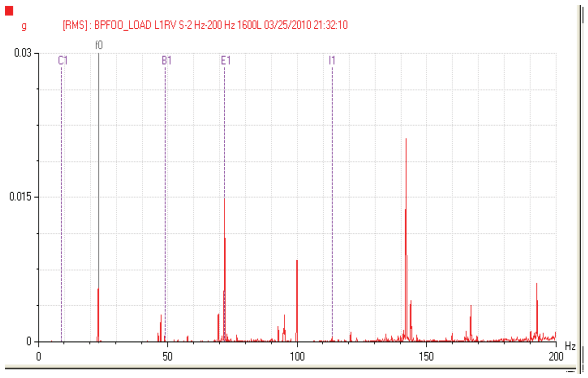


Fig 9. *FFT from the bearing with a defect on the outer race – record from the test rig*

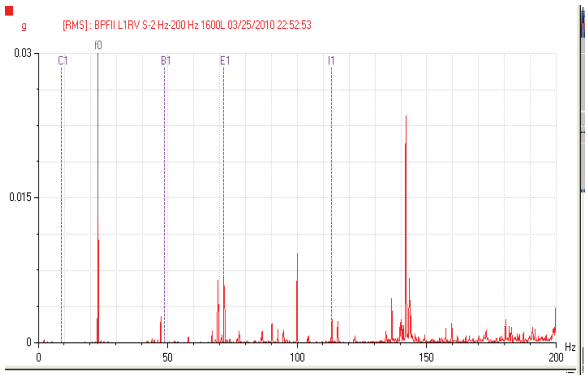


Fig 10. *FFT from the bearing with a defect on the inner race – record from the test rig*

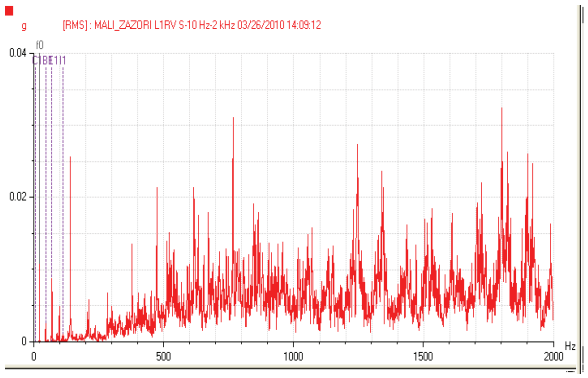


Fig 11. *FFT from the bearing with medium looseness – record from the test rig*

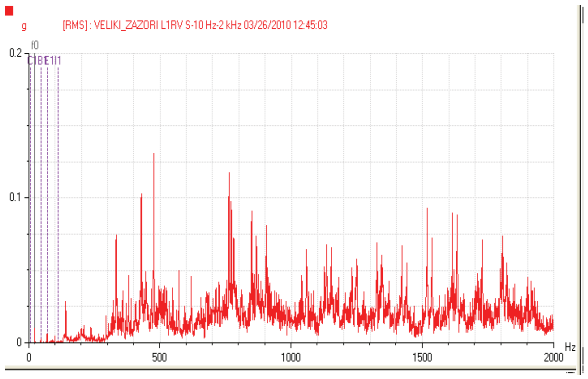


Fig 12. *FFT from the bearing with a defect huge looseness – record from the test rig*

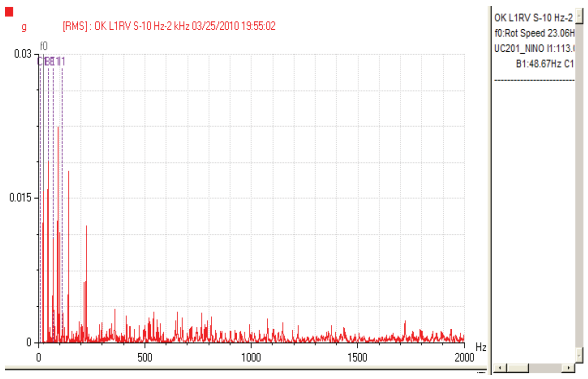


Fig 13. *FFT from the healthy bearing – record from the test rig*

Demodulation / enveloping technique is the advanced signal processing method with its wide application in roller elements bearing condition monitoring in the early stages of defect development. When a rolling element passes over the indentation located at the bearing's race a shock pulse with short duration is generated. Due to its duration compared with the period of impulse generation, this shock pulse can excite natural frequencies of the bearing's housing. Natural frequencies will be excited periodicaly ie. with the frequency equal to the defect frequency of the damaged bearing's component (BPFO, BPFI, BS or FTF). As a result excited natural frequencies will be modulated by the bearing defect frequencies ie. by the frequency of shock pulses repetition in the time domain. Traditional method of enveloping involves bandpass filtering around the excited natural frequency, which is generaly unknown. After filtering the signal is rectified.

First stage in enveloping is the high pass filtering with the aim of eliminating the high amplitude low frequency components.

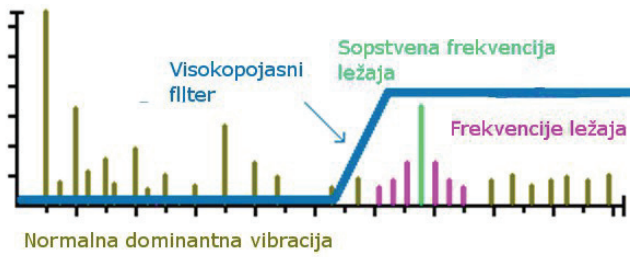


Fig 14. *High pass filtering in enveloping technique*

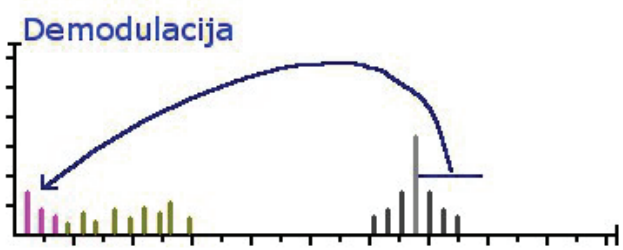


Fig 15. *Sidebands demodulation in enveloping technique*

Cut off frequency of the high-pass filter for bearing vibrodiagnostic and for common speeds of rottaion is generaly chosen to be above 2 kHz. As a result of high pass filtering low pass components are removed. After high pass filtering, modulation sidebands from the right side of the natural frequencies are „translated“ (demodulated) in the zone of low frequencies. After demodulation, signal is subjected to low-pass filter. This filter should remove high frequency components that come from other machine's components and not from a bearing.



Fig. 16. *Low-pass filtering of the demodulated spectra in enveloping technique*

Generaly the cut off frequency of the low-pass is 15-20 times higher than a speed of rotation. As a result of this method an enveloping spectra is obtained with distictive frequency components that originate from a defective bearing. On the figures bellow, envelope spectra generated from a defective bearings from a test rig are shown.

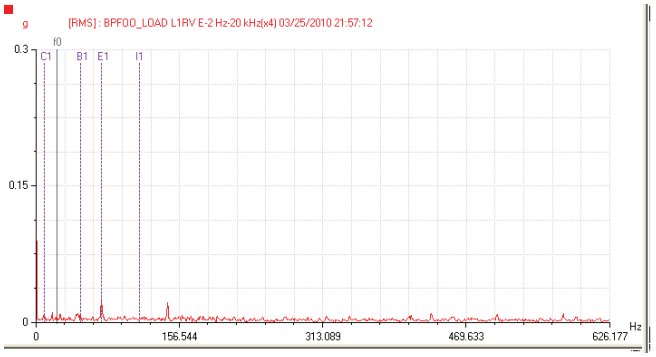


Fig. 17. *Envelope spectra from a bearing with a defect on the outer race - record from the test rig*

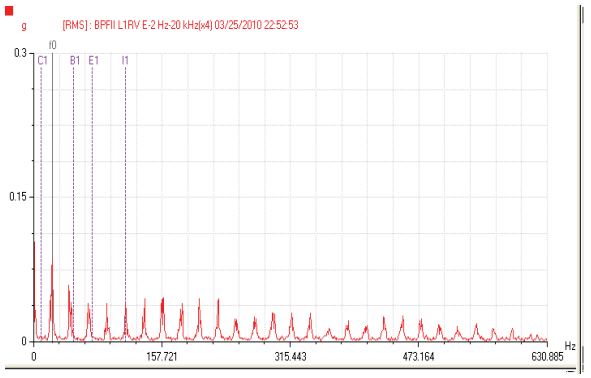


Fig. 18. *Envelope spectra from a bearing with a defect on the inner race - record from the test rig*

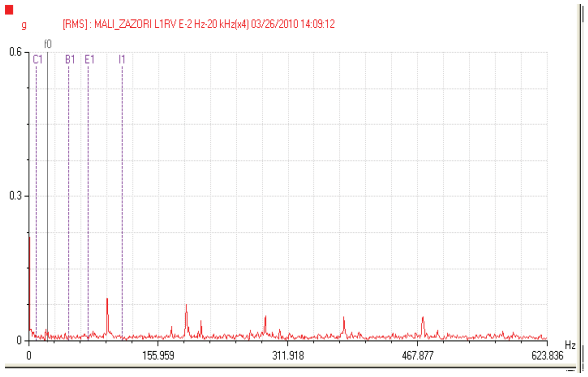


Fig. 19. *Envelope spectra from a bearing with moderate looseness - record from the test rig*

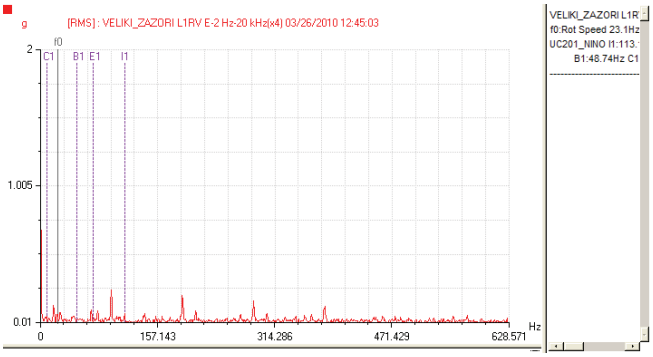


Fig. 20. *Envelope spectra from a bearing with gross looseness - record from the test rig*

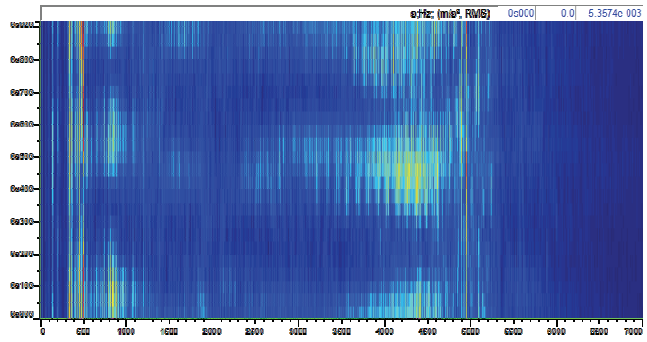


Fig. 22. *STFT from a bearing with the defect on inner race - record from the test rig*

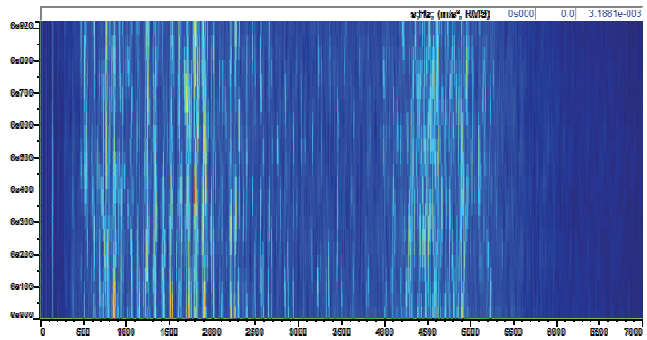


Fig. 23. *STFT from a bearing with small looseness - record from the test rig*

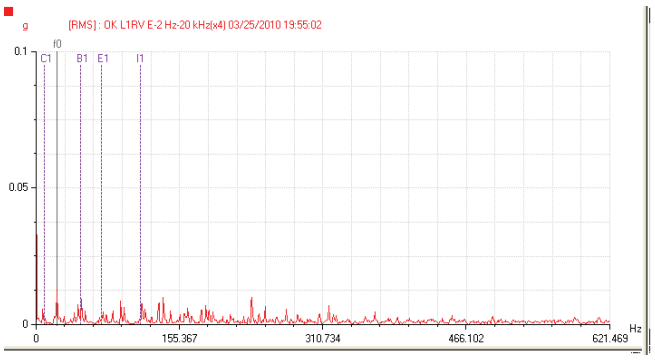


Fig. 21. *Envelope spectra from a healthy bearing - record from the test rig*

Methods of **time-frequency transformations** are widely used in bearing vibrodiagnostics due to the nonstationary nature of the impact phenomena. As a result, time-frequency transformations result in signal presentation in both domains – time and frequency. This makes possible to analyze a frequency contents nonstationarity over the time. The most common used methods for time-frequency transformations in bearing diagnostics are: *Short time frequency transform* - STFT, Wagner – Ville distribution – WVD and wavelet analysis WA.

STFT differs from "regular" FFT by using a moving time windows with specific parameters appropriate for both domains, time and frequency. Moving the time window along the time axis results in presentation of frequency content dependence along the time. Using this method, compared to FFT we get one more dimension i.e. the transformation of signal is two-dimensional (time and frequency).

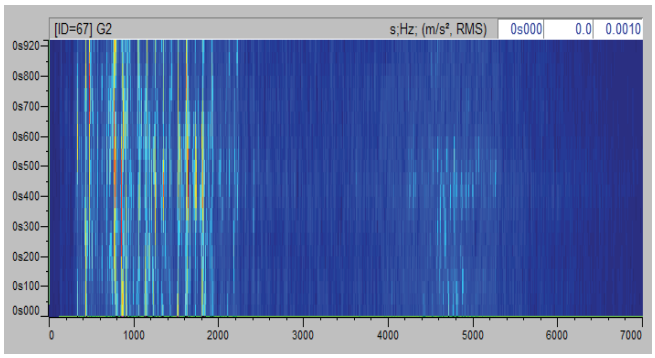


Fig. 24. *STFT from a bearing with gross looseness - record from the test rig*

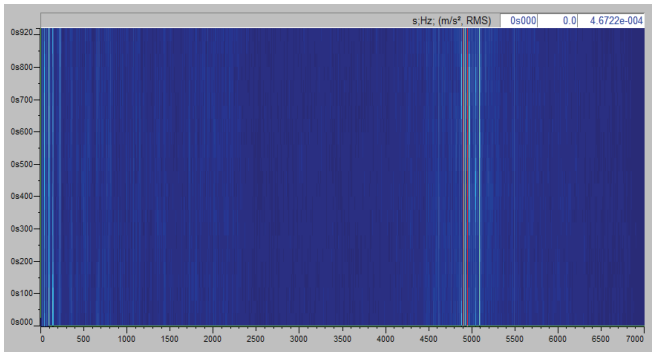


Fig. 25. *STFT from a healthy bearing - record from the test rig*

6. FREQUENCY SPECTRA EVOLUTION WITH DEVELOPMENT OF A BEARING DEFECT

In order to get a reliable information from a defective bearing, as is the case in other fields of vibrodiagnotisc too, it is necessary to known how fault development affects the recorded vibration signal in time and frequency domain. The most common case of a bearing fault that we need to analyse is the fault due to the fatigue crack on one of the four possible bearing's components.

Initial stage of fault development begins with the occurence of fatigue microcrack just bellow the contact surface of the faulty component. It is necessary to note that the level of degradation is small. Components of the vibration signals that come from a bearing are results of small impacts (shock impulses) and friction that occurs due to the abnormal lubrication. These components are located in the high frequency region (from 20kHz and above).

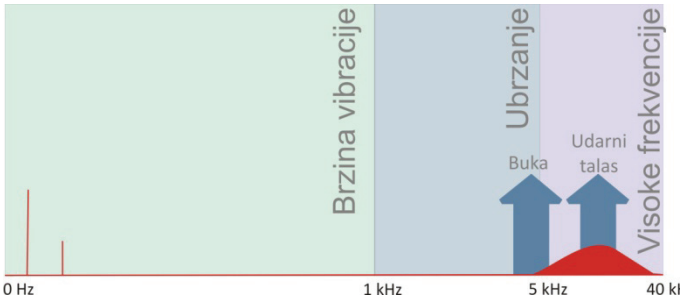


Fig. 26. *Possible shape of FFT in the initial stage of the bearing fault development*

The reliability analysis of the existing detection methods gives the following conslusions:

1. High frequency methods (SPM, SpikeEnergy, PeakVue[5]) in this stage are very reliable and their scalar representatives will grow together with the fault development.
2. Enveloping / demodulation of acceleration vibration signal, in assumption that the cutoff frequencies are well defined, will, despite the bad signal to noise ratio, detect the existence of fault inside the bearing.
3. Frequency spectra – FFT of the vibration velocity will not detect the bearing fault due to the fact that vibration components are in high frequency region. FFT of acceleration signal could give a very limited information on the bearing fault.
4. Time waveform analysis – generaly, for this stage is not useful.

In the second stage of fault development, cracks on the faulty components become larger and wider and therefore the generated impulses could have enough energy to excite the bearing natural frequencies. In this stage the acceleration envelope should give a very clear information on the present defect in the bearing.

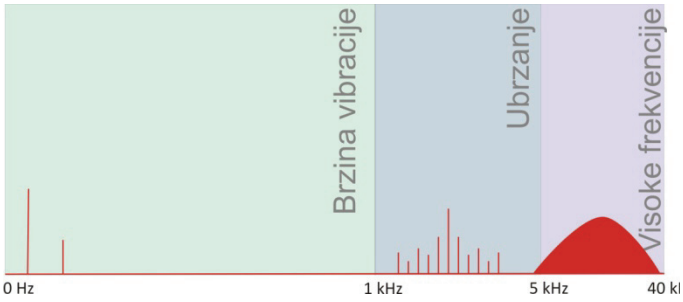


Fig. 27. *Possible shape of FFT in the second stage of the bearing fault development*

The reliability analysis of the existing detection methods gives the following conslusions:

1. High frequency methods – their scalar parameters will still grow together with the fault development.
2. Enveloping / demodulation of acceleration vibration signal will clearly detect the existence of fault inside the bearing.
3. Frequency spectra – FFT of the vibration velocity will not detect the bearing. FFT of acceleration signal will give a very reliable and clear information on the bearing fault.
4. Time waveform analysis – generaly, for this stage is not useful.

In the third stage, bearing faults are larger and there could be more of them in comparison with a previous stage. In this phase it is possible to get the bearing seizure. Typical for this stage is a strong excitement of bearing's natural frequencies. Generaly the wideband noise will be raised, both, in FFT and envelope spectra.

The reliability analysis of the existing detection methods gives the following conslusions:

1. High frequency methods – their scalar parameters will still grow together with the fault development.
2. Enveloping / demodulation of acceleration vibration signal will detect the existence of fault inside the bearing but the raised noise will start to mask the bearing frequencies.
3. Frequency spectra – FFT of the vibration velocity and acceleration will give a very reliable and clear information on the bearing fault.
4. Time waveform analysis – generaly, is very useful for this stage.

The third stage is generaly a point where the bearing should be replaced, if possible. If not the vibration analyst should monitor the vibration parameters of the bearing on weekly basis.

[5] *These methods are not considered as universal since they require using vibration acquisition devices and softwares from specific vendors. Therefore, they are not analyzed in this paper.*

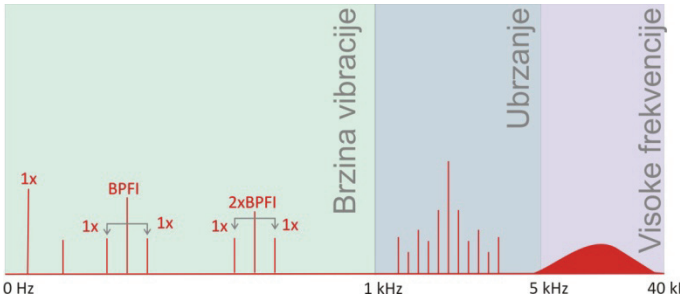


Fig. 28. *Possible shape of FFT in the third stage of the bearing fault development*

If the bearing is still left in operation, initial faults on one bearing's component will damage the other bearing's components. Due to the indentations smearing, it is possible to get lower high frequency components, compared to the previous stage.

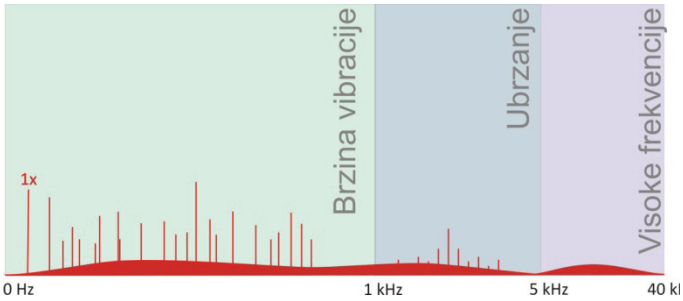


Fig. 29. *Possible shape of FFT in the fourth stage of the bearing fault development*

Due to the material flaking loosenes in the bearing grows. This directly affects the bearing geometry and this results in noisy operation and changing the bearing defect frequencies.

The reliability analysis of the existing detection methods gives the following conslusions:

1. High frequency methods – they are very unreliable in this stage due to the lowering of high frequency components. The bearing faults develops while the high frequency parameters are decreasing.
2. Enveloping / demodulation of acceleration vibration signal could detect the existence of fault inside the bearing but the raised noise very often mask the useful components.
3. Frequency spectra – FFT of the vibration velocity and acceleration will give a very reliable and clear information on the bearing fault.
4. Time waveform analysis – generaly, is very useful for this stage since the impacts and amplitude modulation are visible.

The bearing in the forth stage must be immediately replaced.

7. CONCLUISON

Vibration analysis is the proven and the most reliable method for identification of faults inside the roller elements bearings. The success and the content of the information we get from the measurement are highly dependent on the signal processing methods that were applied. The paper demonstrated that there is no unique universal method for monitoring the development of a fault inside the bearing from its mounting up to bearing's wreck.

REFERENCES

[1.] Zuber N., "Automatizacija identifikacije otkaza rotirajucih mašina analizom mehanickih vibracija", doktorska disertacija, Fakultet Tehničkih Nauka Univerziteta u Novom Sadu, 2010.

[2.] James Taylor, Wyndell Kirkland: The Bearing Analysis Handbook: A Practical Guide for Solving Vibration Problems in Bearings: Vibration Consultants, 2004. ISBN 0-9640517-3-7

[3.] Zuber N., Ličen H.: Savremene metode praćenja stanja ležajeva na bazi merenja i analize mehaničkih vibracija, Održavanje mašina i opreme, 2006.

[4.] Zuber N, Licen H., Bajric R.: An innovative approach to the condition monitoring of excavators in open pits mines, Technics technologies education managment, Volume 5, number 1, 2010, pp 3-10, ISSN 1840-1503

[5.] Mobius Institute Vibration training manual – category III

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

APPLICATION OF ARTIFICIAL INTELIGENCE METHODS IN AUTOMATED VIBRODIAGNOSTICS OF ROTATING MACHINES IN MINING INDUSTRY – A CASE STUDY

Ninoslav Zuber[1]

[1] Faculty of Technical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, Novi Sad, email: zuber@uns.ac.rs

Abstract – *Paper deals with the automation of fault identification in roller element bearings and gears by the means of artificial neural networks and vibration signal analysis. A case study with several identified faults in gearboxes and drives on a mine strip rotating excavator is presented.*

1. INTRODUCTION

Rotating machines are considered as crucial equipment in every plant. Roller element bearings are the most used mechanical parts in the rotating equipment and they are treated as the primary cause of unscheduled stops and machine breakdown. These unscheduled and sudden failures result in loss of production, reduction of machine availability and could even cause serious injuries and loss of human lives. Therefore, a development and implementation of a system for an early detection of faults is of great interest. Today, various testing and analysis methods are used for the roller element bearing condition monitoring and evaluation. The most utilized methods are:

1. Vibration measurement and analysis – vibrodiagnostics
2. Noise measurements
3. Temperature measurement and infrared analysis
4. Oil analysis and wear particle analysis,

where the analysis of vibrations acquired from the bearing housings and real-time or post process signal analysis is the most reliable one. This is the basis of vibrodiagnostics.

If we analyze the existing trends in the development of condition monitoring techniques, we see that there are many requirements to do the job more efficient. How can we achieve this? There are two parallel approaches: to perform the data collection in more efficient manner and to automate the methods for fault identification and quantification. For example, will we still in the future monitor most of the equipment using offline methods on a monthly basis? Probably not. One the other hand will we still in the future monitor more frequently critical machines in our assets? Probably yes. Based on existing and developing economic trends and development of IT technologies, several scenarios will be seen in the future:

1. There will be less manpower involved in the collection of data from the machines. Economic trends, merging small companies into global multinational groups, spatial separation of management and research and development departments from the production are just some of the facts that will initiate reduction of people in maintenance groups.
2. The existence of centralized databases for hosting all the necessary information on condition of all machines from remote locations.
3. Vibration signals and their scalar representatives will be forwarded directly to vibration analysts. Today, most of the time with offline monitoring, the vibration analyst performs an analysis of vibration signals that were acquired by his colleague – vibration technician.

Results of a vibration analysis on a particular machine is performed on the basis of combination of knowledge and experience of the vibration analyst. Skilled vibration analyst will use his/her knowledge in identification of rules that follow specific fault types. In reality it takes many years of permanent education and practical experience in solving vibration problems on rotating machinery. Therefore, it is not a rare situation that these engineers are the oldest ones in their maintenance groups. Also sometimes there are moved to a new position so they do not deal with vibration analysis any more. In the most promising case, younger maintenance engineer is put on their former position. The problem is that this new engineer does not have the knowledge and experience his former colleague had. In real life , members of maintenance departments are under a high pressure due to the constant requirement of their management: to do more with less manpower. The size of the maintenance groups inside the plant is reducing or the existing engineers are getting more and more responsibilities. In such a situation, even the most promising vibration analysts don't have time for detailed analysis of acquired vibration data from their machines. Serious problem can occur in the scheduled or unscheduled absence of their vibration analyst. All of the above mentioned, implies the absolute need for feeding the knowledge and experience in identification of faults into an intelligent decision making system so that these information is available to less skilled maintenance engineers when required.

Methods of artificial intelligence, applied in automation of vibrodiagnostical methods are a potential solution for the described problems. They provide techniques and tools for exploration of a previously stored knowledge and experience. In addition, it should be noted that these algorithms need much less time than the vibration analyst need to solve the problem. As a result, application of artificial intelligence leaves much more time for vibration analyst available for his / her other activities. Maybe the biggest justification of artificial intelligence methods application in vibrodiagnostics is where multiple faults on the rotating machine are present. In real life, this is a very common situation. For example,

roller element bearings could be damaged by other faults like unbalance, misalignment, worn gear etc. At some moment, multiple faults will be present on the machine during vibration signal recording. Majority of vibration analyst and especially those with lower level of certification are trained to identify a single and isolated machine fault. In the presence of multiple faults advanced multichannel vibration recordings and most advanced signal processing techniques are used. Then recorded vibration spectra are compared against well-known spectral patterns in order to find a case, which looks similar to the recorded spectra. Such an approach very often leads to incorrect vibrodiagnostical conclusions due to the superposition of faults. Even in the case with experienced and trained vibration analyst with sophisticated vibration measurement equipment and signal processing software, he / she can miss the primary cause of vibration due to its lower amplitude components compared to amplitudes of secondary faults. The typical case is damaged bearing that will lead to developing looseness. One of the primary goals of every maintenance department is achieving the level of proactive maintenance, which, in its simplest explanation, seeks for root causes, which lead to secondary faults. Therefore, identification of all the present faults on the machine and their correlation (cause-effect) is necessary and the implementation of artificial intelligence methods in identification of fault has a huge potential.

2. ARTIFICIAL INTELLIGENCE METHODS IMPLEMENTATION IN VIBRODIAGNOSTICS

Artificial neural networks (ANN), proven method of artificial intelligence, are parallel processing systems that can work in two mode:

1. Supervised mode – where training and adaptation of network's coefficients is based on known examples,
2. Unsupervised mode – where unsupervised neural network finds complex relations between input features of the input vectors.

Neural networks, among other applications, can be used for automation of vibrodiagnostics through pattern recognition, where input scalar features (different scalar representations of vibration signal from time and frequency domain) pattern is recognized and related to specific fault. There are several architectures of neural networks. In automation of vibrodiagnostics and fault identification, multiple layer perception neural network are used.

For unsupervised training i.e. for description analysis of multivariable sets of input data Kohonen's Self Organized Feature Maps (SOFM) are widely used. Inside the SOFM vector of input features are transformed in one-dimensional or two-dimensional feature maps. Neurons of self organized feature maps describe the unknown input patterns in the form of their weighing coefficients.

3. EXPERIMENTAL SETUP

As a case study of a successfully applied adaptive remote condition monitoring with implementation of methods of automated vibrodiagnostics using neural networks, an online monitoring strain and vibration monitoring system, installed on a bucket wheel excavator SR1300.24/2 at Kolubara open pit coal mine is presented. It is a part of the Project [2] financed by the Serbian Ministry of science and technological development.



Fig 1. *SRs 1300.24/2.5 bucket wheel excavator located at Kolubara open pit mine (field D)*

This project was initiated by the Faculty of Technical Sciences, University of Novi Sad, Serbia and the Kolubara open pit mines. The main motivation for the above mentioned concept implementation were the facts that this excavator:

1. Is a highly critical machine for the coal mine production
2. Experiences high levels of non-stationary dynamic loads. The end user was therefore interested to see if the levels of these dynamic loads are much higher than the declared loads and therefore proposed an installation of intelligent online monitoring system for the measurement and analysis of stresses and vibration levels on the excavator with the possibility to give a realistic diagnostic and prognostic conclusions about the operational state of the excavator.

As a result a combined system of remote monitoring was proposed and installed. The proposed monitoring system monitors not only vibration signals from the drives and gearboxes but also stresses and strains in the critical parts of the excavator's construction. The strain measurements are done using strain gauges while the vibration measurements are based on IEPE accelerometers. For the strain measurement, the universal measuring device MGCplus and CatMan software from Hottinger Baldwin Messtechnik was used, while for the vibration measurements a multichannel OneproD MVX Premium system and an accompanying XPR software from 01dB-Metravib, Areva was installed.

Measurement points for the strain measurements are:

1. Holders of the bucket wheel arms (2 measurement points),
2. Bucket wheel arms, left side (6 measurement points),
3. Bucket wheel arms , right side (6 measurement points),
4. Main column, left side (6 measurement points),
5. Main column, right side (6 measurement points),
6. Rotating platform (12 measurement points with 4 rosettes),
7. Counterweight holder (8 measurement points).

On the other side, the absolute vibrations are measured on the following drives:

1. Bucket wheel drive with gearbox (10 radial vibrations and a tacho),
2. Rotating platform drive and gearbox, left and right drives (10 radial vibrations and a tacho),
3. Conveyer belt drive and a gearbox (5 radial vibrations),
4. Drives and gearboxes for the bucket wheel elevation (10 radial vibrations).

Vibration parameters for monitoring of the drive's operating states are:

- SCALAR (overall values) parameters: RMS level of vibration velocity according to the ISO 10816, overall level of vibration acceleration (in several frequency bands), Defect factor for the ball bearing state evaluation, Kurtosis factor, and many frequency peak extractions (first 5 harmonics of the main shafts and first 5 harmonics of the gear mesh frequencies).
- VECTOR values (signals): Frequency spectra in 3 different frequency bands with 3200 lines of resolution (2 - 200 Hz, 2 – 2 000 Hz, 2 – 20 000 Hz), Time waves 0 - 2.56 kHz with 4 096 point synchronously acquired and averaged with a tacho signal.

In addition, the elevation angle of the bucket wheel holders is measured by an analog inclinometer. For the acquisition triggering i.e. for the definition of the operating conditions, digital inputs of the MVX device are used (Digital input #1 – bucket wheel drive gripe, Digital input #2 – rotating platform drive gripe, Digital input #3 – elevation drives gripe, Digital input #4 – moving direction detection (detection of direction changing left-right and right-left). Also, as a governing parameter of the operating condition definition, the bucket wheel torque measurement is performed by measuring bending stresses at the the third support of the bucket wheel.

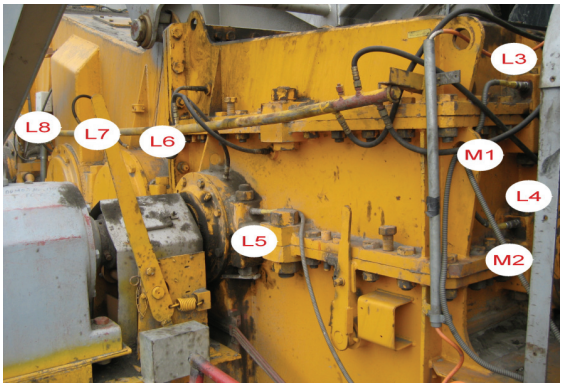


Fig 2a. *Measurement point locations at the bucket wheel drive gearbox*

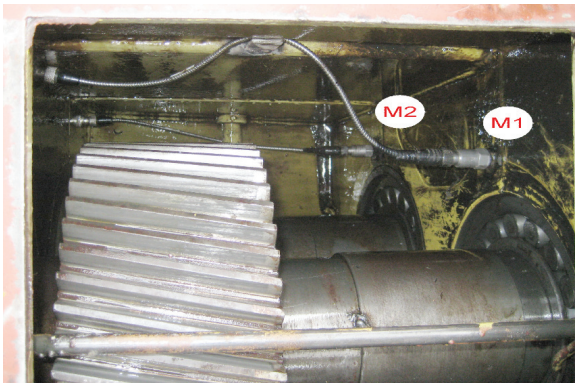


Fig 2b. *Measurement point locations inside the bucket wheel drive gearbox*



Fig 3. *Third support of the bucket wheel where the strain gauges were applied for torque measurement*

Both, above-mentioned measuring devices are TCP/IP based and are connected to the excavator's local area network. On the same LAN, the dedicated data server, with OneproD XPR 300 and HBM CatMan 5.2R5 software installed, is connected and placed in the operator's cabin. OneproD XPR software is responsible for the vibration data analysis while the CatMan software acquires and analyzes the strain measurement signals. In addition, the dedicated software, responsible for preprocessing and storing special scalar vibration features for the purpose of subsequent data exploration using methods of artificial intelligence, written by the author is installed.

Local area network from the excavator is, over the dedicated Wireless system, connected to the first AP (access point) which is located at the periphery of the open pit mine. This AP is, using wireless local area network (WLAN), connected to two client computers. One client PC is for the "Kolubara metal company" maintenance group while the other one is for the authors of this paper. Simplified architecture of the described system is shown on the Figure 4.

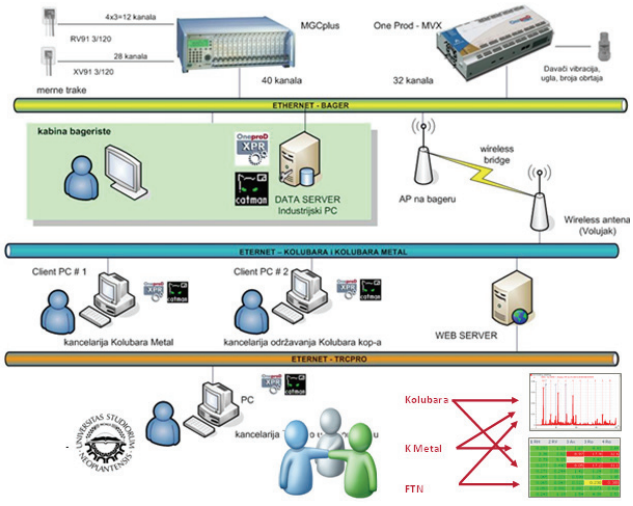


Fig 4. *Remote bucket wheel excavator monitoring scheme*

The monitoring system's structure defined and installed in the described way enables a real-time insight into the excavator's operating state by the personnel at the excavator, the personnel from the maintenance team of the coal mine, Vibration specialists from the University of Novi Sad.

4. RESULTS

Just several weeks after being installed, the system gave some very interesting information regarding the nature and levels of dynamic loads as well as regarding the very progressive development of failures on some ball bearings of the monitored drives and gearboxes.

A classic vibration monitoring approach by measuring, calculating and comparing the current vibration parameters with their statistically derived alarm values is possible at drives where the stationary working conditions are present (for example at conveyer belt drive and a gearbox). On the other hand, at the drives where a non-stationary operating condition is present (rotating shaft's speed and load changes significantly) a much more sophisticated approach is needed since the level of the driving torque combined with the actual shaft's speed affects the level and the content of the vibration spectra.

Taking into a consideration that there is a strong dependence between the vibration values and the driving torque an automated online vibration diagnostics presents a real engineering challenge. Generally, there are two different approaches to the possible solution of this problem:

1. Normalization of data: In this approach, we normalize the vibration features in order to effectively cancel out the influence of the torque variability. This approach is effective in cases where we can identify a single influencing and continuous parameter.
2. Another approach, which could be appropriate in cases where the relation between the governing parameter and vibration features is nonlinear, is to divide the complete range of governing parameter into several bands i.e. to define several separate operating conditions and to analyze them separately by means of defining special vibration features as well as different sets of alarm values for each operating condition.

For the purpose of automatic vibration diagnostic of a bucket wheel excavator we utilized the second approach: the shaft speed and the driving torque are measured in real-time, based on their values an operating condition detection takes place and an acquisition setup for this operating condition is performed. When completed, vibration features are compared to the alarm values that correspond to the identified operating condition.

After the online system is installed, several interesting machine failures were reported. Here two of them are presented:

1. Failure of a roller elements ball bearing at the input stage of a gearbox from the bucket wheel drive
2. Gear failure from the gearbox of the conveyor belt

These failures i.e. recorded signals during the period if their development were used to build, train and test an artificial neural network as a tool for automated vibrodiagnostic of the main drives of the bucket wheel excavator.

4.1 Case study 1 – bucket wheel gearbox bearing failure

In April 2009, the maintenance department informed the author on high temperatures and strange noise coming from the first bearing (measurement point L3 from figure 2.) on the first input stage of a bucket wheel gearbox. Analysis of recorded time waveform signals and frequency spectra will indicate to skilled and trained vibration analyst that there is an ongoing bearing failure (figures 5 and 6).Time waveform contains nonsynchronous peaks while the frequency spectra contains a wideband noise.

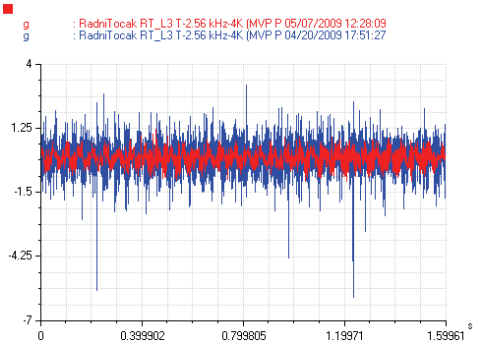


Fig 5. *Time waveform, measurement location L3, healthy (red) and damaged (blue) bearing*

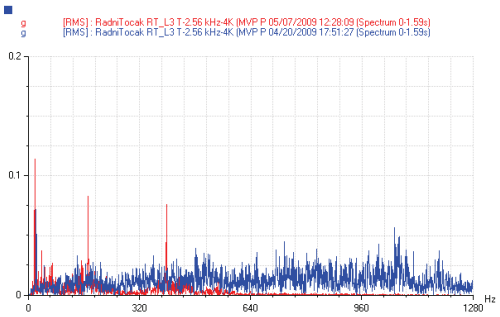


Fig 6. *Frequency spectra, measurement location L3, healthy (red) and damaged (blue) bearing*

Scalar features that were used for input vector of a neural network were chosen based on research conducted in [1]: bearing defect factor DEF, overall acceleration in band 2 Hz - 2 kHz, overall acceleration in band 2 Hz - 500 Hz, overall acceleration in band 500 Hz – 1 000 Hz, overall acceleration in band 1 000 Hz - 2 000 Hz, Kurtosis parameter and Peak-Peak value from a time waveform.

Under assumption that the rate of bearing degradation is linear input vector is labeled. Recording that were inside the input vector were from a time before a high temperature was evidenced up to the time when a bearing was replaced. Three labels were defined: „Z1" (healthy state, green label), „Z2" (alarm state, yellow label) and „Z3" (highly damaged bearing, red label). Table 1. shows the mean values for the used vibration features for different labels.

Table 1 *Average values of vibration features for different labels*

Feature	Z1	Z2	Z3
Acc	0.677816	0.870405	0.866536
Acc_2_500	0.461794	0.557893	0.560038
Acc_500_1000	0.414687	0.561460	0.550282
Acc_1000_2000	0.275421	0.382861	0.403252
PeakPeak	5.044780	6.461899	6.555252
Def	3.621043	4.171950	4.596872
Kurtosis_MVX	0.677816	3.263370	3.286046

For the training of SOFM in unsupervised mode input vector with the mentioned scalar features, but without labels was used. SOFM development, training, and testing were performed using a Matlab simulation software package. As a result, a SOFM with the quantization error of 0.3497 is generated. From the distance matrix and the topology matrix with labeled neurons, it can be seen that the clustering is more than satisfactory.

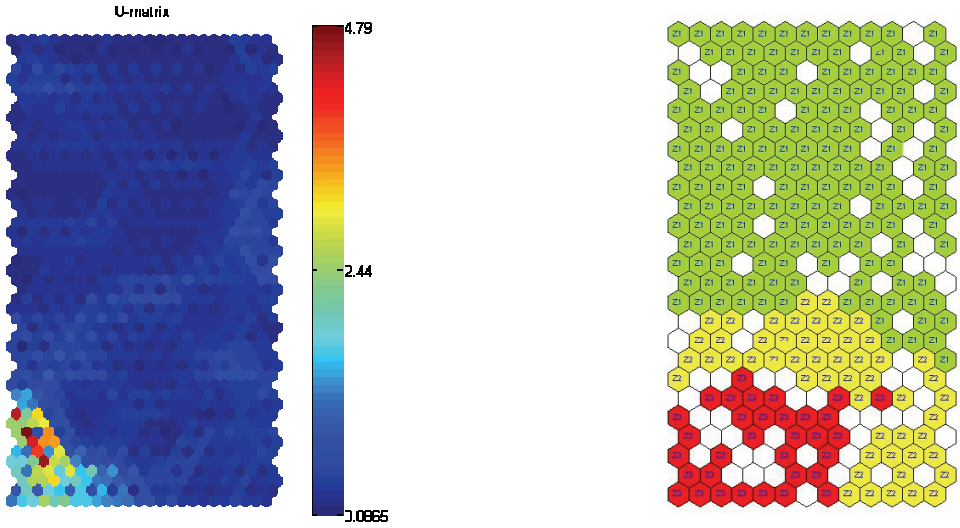


Fig 7. *Distance matrix and matrix topology with labels overlaid*

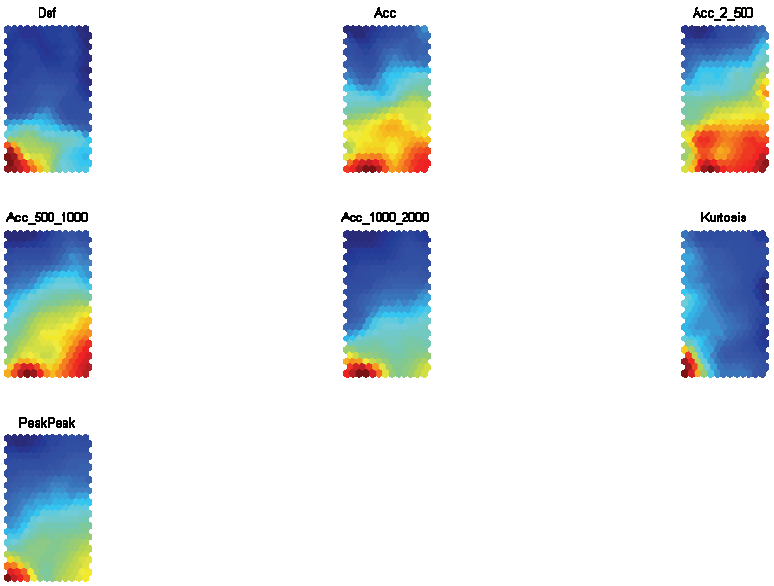


Fig 8. *Component planes for used vibration features of SOFM*

Labeled input vector was then used to design an artificial neural network. Based on experiences from [1], a multiple layer perceptron neural network with back propagation architecture was used. More than 30 different ANNs were tested and the results are presented on the tables bellow:

Table 2 *Configuration of ANN and the results of their training and testing*

Rb	Net. name	Training perf.	Test perf.	Validation perf.	Training algorithm	Error function	Hidden activation	Output activation
1	MLP 8-5-3	92.12903	92.72727	90.90909	BFGS 25	Entropy	Logistic	Softmax
2	MLP 8-6-3	92.51613	93.33333	92.72727	BFGS 25	SOS	Logistic	Identity
3	MLP 8-5-3	88.00000	88.48485	89.69697	BFGS 22	SOS	Identity	Identity
4	MLP 8-5-3	91.61290	92.12121	88.48485	BFGS 27	Entropy	Identity	Softmax
5	MLP 8-11-3	92.77419	92.72727	92.72727	BFGS 33	SOS	Tanh	Tanh
6	MLP 8-10-3	92.51613	92.72727	89.69697	BFGS 53	SOS	Tanh	Exponential
7	MLP 8-4-3	86.32258	88.48485	85.45455	BFGS 21	SOS	Identity	Exponential
8	MLP 8-6-3	91.61290	92.12121	88.48485	BFGS 26	Entropy	Identity	Softmax
9	**MLP 8-5-3**	**93.80645**	**94.54545**	**94.54545**	**BFGS 58**	**Entropy**	**Logistic**	**Softmax**
10	MLP 8-5-3	92.12903	93.33333	91.51515	BFGS 24	Entropy	Logistic	Softmax
11	MLP 8-6-3	91.35484	92.12121	90.30303	BFGS 19	Entropy	Identity	Softmax
12	MLP 8-12-3	93.41935	95.15152	92.12121	BFGS 45	Entropy	Exponential	Softmax
13	MLP 8-5-3	76.90323	80.60606	76.96970	BFGS 9	SOS	Identity	Logistic
14	MLP 8-4-3	69.80645	64.84848	67.27273	BFGS 22	SOS	Tanh	Identity
15	MLP 8-11-3	90.45161	92.12121	90.30303	BFGS 11	Entropy	Exponential	Softmax
16	MLP 8-4-3	91.48387	92.12121	89.69697	BFGS 27	Entropy	Tanh	Softmax
17	MLP 8-5-3	93.41935	93.33333	92.12121	BFGS 44	Entropy	Tanh	Softmax
18	MLP 8-7-3	90.96774	92.72727	87.87879	BFGS 26	Entropy	Identity	Softmax
19	MLP 8-5-3	89.54839	89.69697	89.69697	BFGS 15	SOS	Identity	Logistic
20	MLP 8-11-3	92.38710	93.93939	89.69697	BFGS 20	Entropy	Exponential	Softmax

As it can be seen from the table 2, ANN number 9 gave the maximum performance i.e. the minimal prediction error, so this ANN was chosen for automatic fault identification on the analysed machine.

4.2 Case study 2 – Bearings failure from the drive of the conveyor belt

In October 2009 maintenance department informed the author on higher than normal tempertaures on both bearings on the main drive of the conveyor belt are damaged. Detailed analysis in time and frequency domains show that bearings (measurement locations L1 and L2 on the figure 9) are damaged.

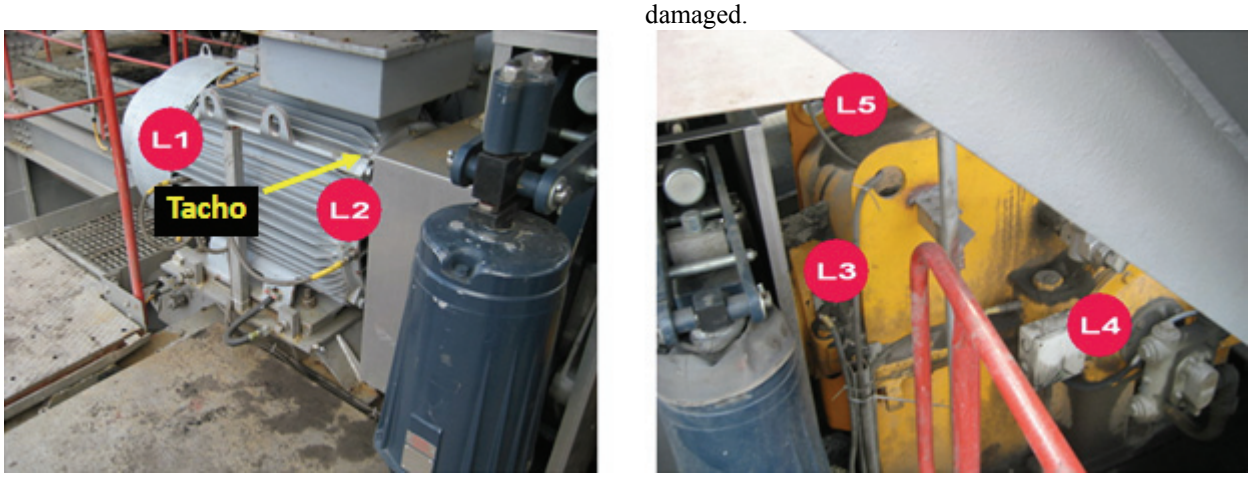


Fig 9. *Drive and a gearbox of the conveyor belt*

As in previous case it was assumed that rate if bearing fault development is linear in time and this was used in labeling the records in input vector. Input vector includes vibration recordings severel months before the rise in temperature up to bearings replacement. Four labels are defined: healthy bearing – yellow label „OK“, bearing with small looseness – red label „Z1“, bearing with moderate looseness – green label „Z2“ and bearing with gross looseness – blue label „Z3“. Same labels were used for both bearings L1 and L2.

Scalar features that were used for input vector of a neural network are: overall acceleration in range 2 Hz - 20k Hz, Kurtosis parameter and Defect factor. The length of the input vector is 23 948 recordings for bearing L1 and 38181 for bearing L2.

Table 3 *Average values of vibration features for different labels, bearing L1*

Feature	OK	Z1	Z2	Z3
Def	1.683702	5.595297	6.655560	8.810003
Acc	0.561619	0.645980	1.505755	2.734469
Kurt	3.170533	3.272425	3.001480	2.862855

Table 4 *Average values of vibration features for different labels, bearing L2*

Obeležje	OK	Z1	Z2	Z3
Def	0.335009	3.453306	3.535962	4.500217
Acc	0.331179	0.572045	1.410454	2.332438
Kurt	4.815412	3.085003	3.090784	3.124968

Input vectors for both bearings were used in order to design a SOFM. Quantization error for bearing L1 is 0.1337 and for bearing L2 is 0.0738.

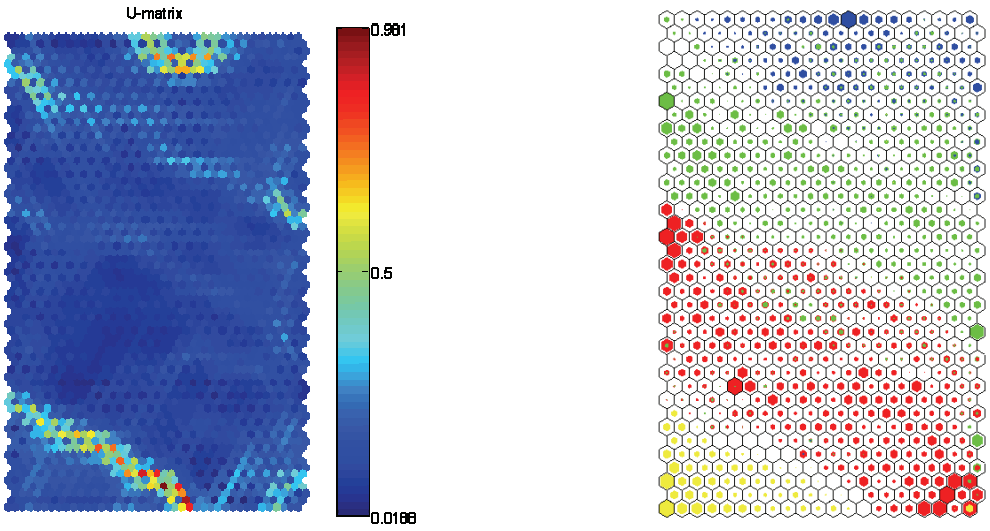


Fig 10. *Distance matrix and matrix topology with labels overlaid, bearing L1*

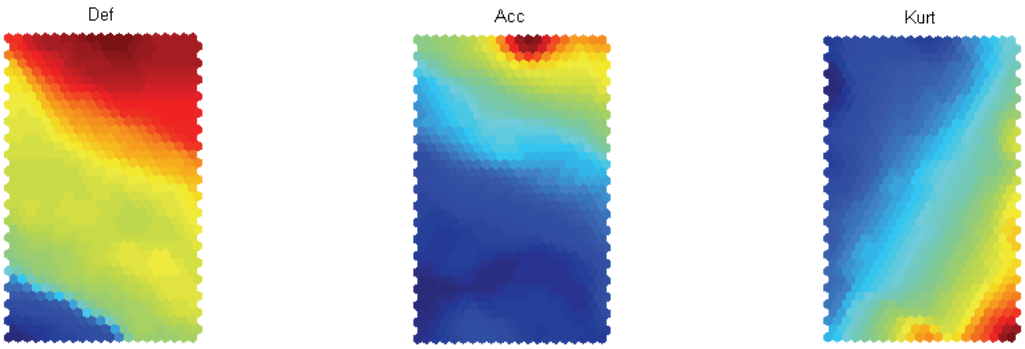


Fig 11. *Component planes for used vibration features of SOFM, bearing L1*

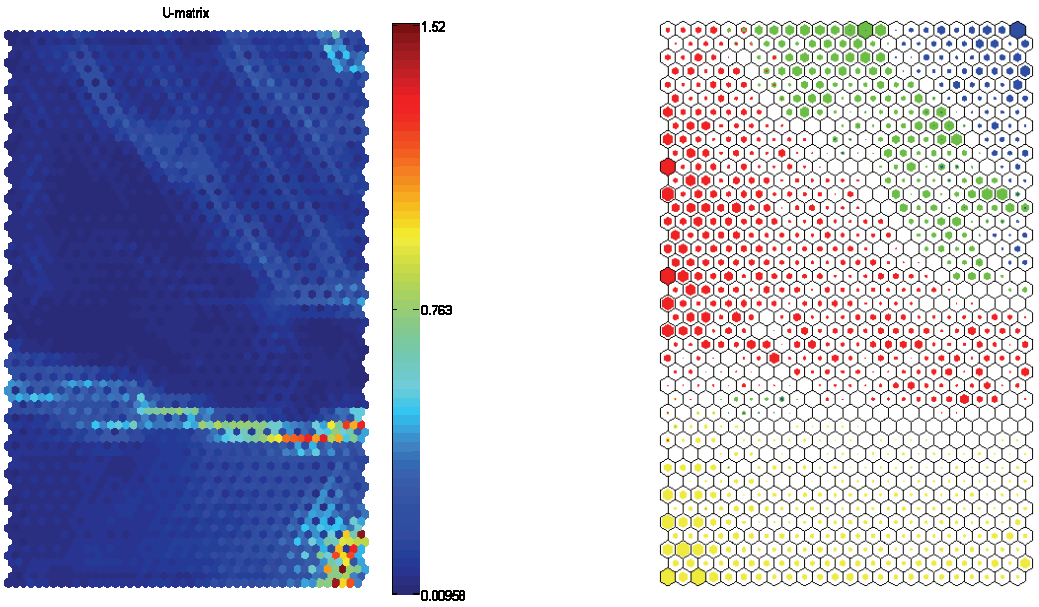


Fig 12. *Distance matrix and matrix topology with labels overlaid, bearing L2*

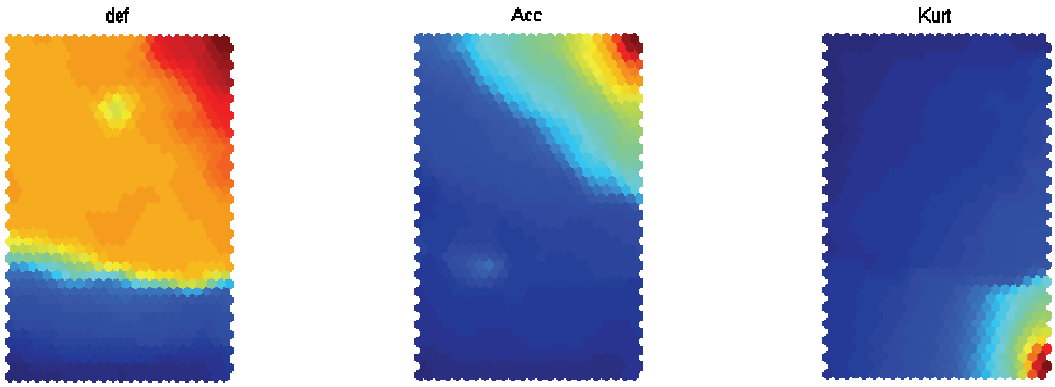


Fig 13. *Component planes for used vibration features of SOFM, bearing L2*

Labeled input vectors for both bearings were used to design an artificial neural network. Results are shown on the tables bellow.

Table 5 *Configuration of ANN and the results of their training and testing, bearing L1*

No	Net. name	Training perf.	Test perf.	Validation perf.	Training algorithm	Error function	Hidden activation	Output activation
1	MLP 3-9-4	82.04379	81.62584	81.26392	BFGS 17	Entropy	Exponential	Softmax
2	MLP 3-4-4	57.50164	56.23608	57.62806	BFGS 12	Entropy	Identity	Softmax
3	MLP 3-5-4	93.09789	93.34633	93.06793	BFGS 71	SOS	Tanh	Exponential
4	MLP 3-10-4	92.47151	92.53898	91.98218	BFGS 46	SOS	Identity	Logistic
5	MLP 3-3-4	92.22096	92.42762	92.12138	BFGS 36	Entropy	Exponential	Softmax
6	MLP 3-9-4	93.27089	93.51336	93.09577	BFGS 45	Entropy	Exponential	Softmax
7	MLP 3-5-4	92.88910	93.09577	92.95657	BFGS 76	SOS	Tanh	Tanh
8	MLP 3-10-4	94.33872	94.48775	94.59911	BFGS 52	Entropy	Tanh	Softmax
9	MLP 3-10-4	93.43196	93.84744	93.95880	BFGS 59	Entropy	Logistic	Softmax
10	MLP 3-9-4	91.52300	92.23274	91.50891	BFGS 30	SOS	Exponential	Identity
11	MLP 3-10-4	94.15976	94.45991	94.29287	BFGS 54	Entropy	Tanh	Softmax
12	MLP 3-10-4	91.99427	92.56682	91.98218	BFGS 33	SOS	Identity	Logistic
13	MLP 3-5-4	79.93796	79.73274	80.59577	BFGS 32	SOS	Logistic	Exponential
14	MLP 3-4-4	93.24107	93.54120	93.23497	BFGS 61	SOS	Logistic	Identity
15	MLP 3-5-4	78.21392	79.25947	79.73274	BFGS 16	Entropy	Exponential	Softmax
16	MLP 3-3-4	93.86745	93.90312	93.62472	BFGS 151	Entropy	Tanh	Softmax
17	MLP 3-3-4	93.09193	93.31849	92.90089	BFGS 47	Entropy	Identity	Softmax
18	MLP 3-9-4	86.58355	85.71826	86.10802	BFGS 23	SOS	Tanh	Tanh
19	**MLP 3-10-4**	**94.36855**	**94.59911**	**94.62695**	**BFGS 63**	**Entropy**	**Logistic**	**Softmax**
20	MLP 3-6-4	93.76603	94.37639	93.98664	BFGS 78	Entropy	Logistic	Softmax

Table 6 *Configuration of ANN and the results of their training and testing, bearing L2*

No	Net. name	Training perf.	Test perf.	Validation perf.	Training algorithm	Error function	Hidden activation	Output activation
1	MLP 3-4-4	97.88603	97.97415	97.85190	BFGS 124	SOS	Logistic	Identity
2	MLP 3-9-4	98.73162	98.81243	98.72511	BFGS 32	Entropy	Identity	Softmax
3	MLP 3-6-4	98.23400	98.42822	97.99162	BFGS 57	SOS	Exponential	Logistic
4	MLP 3-10-4	99.49115	99.54593	99.56340	BFGS 81	Entropy	Tanh	Softmax
5	MLP 3-5-4	97.97957	98.06147	97.64233	BFGS 40	Entropy	Exponential	Softmax
6	MLP 3-10-4	88.12437	88.57841	88.31645	BFGS 22	SOS	Identity	Exponential
7	MLP 3-4-4	88.02709	88.50856	88.21167	BFGS 31	SOS	Tanh	Identity
8	MLP 3-6-4	97.50814	97.53755	97.25812	BFGS 46	Entropy	Exponential	Softmax
9	MLP 3-10-4	97.99828	98.07894	97.85190	BFGS 29	SOS	Exponential	Identity
10	MLP 3-4-4	93.94246	93.81767	94.06217	BFGS 17	Entropy	Exponential	Softmax
11	MLP 3-8-4	97.70644	97.81698	97.32798	BFGS 34	Entropy	Exponential	Softmax
12	MLP 3-5-4	99.10203	99.05693	99.19665	BFGS 56	Entropy	Tanh	Softmax
13	**MLP 3-7-4**	**99.13196**	**99.12679**	**99.26650**	**BFGS 76**	**Entropy**	**Logistic**	**Softmax**
14	MLP 3-4-4	98.99727	98.95215	98.81243	BFGS 94	Entropy	Logistic	Softmax
15	MLP 3-6-4	97.82991	97.92176	97.65980	BFGS 71	SOS	Tanh	Tanh
16	MLP 3-4-4	98.72414	98.67272	98.69019	BFGS 51	Entropy	Identity	Softmax
17	MLP 3-8-4	98.63434	98.63779	98.42822	BFGS 147	SOS	Tanh	Exponential
18	MLP 3-3-4	97.51188	97.79951	97.24066	BFGS 60	Entropy	Exponential	Softmax
19	MLP 3-8-4	88.09069	88.38631	88.22913	BFGS 17	SOS	Identity	Tanh
20	MLP 3-10-4	98.91121	98.84736	98.96961	BFGS 52	Entropy	Exponential	Softmax

5. CONCLUSION

Supervised and unsupervised artificial neural networks, as methods of artificial intelligence, are very efficient tools in automation of fault identification and quantification in rotating machines. However to use their full potential a detailed manual vibration diagnosis must be used in order to select the right vibration parameters as scalar features for their training, testing and validation of results.

REFERENCES

[1.] Zuber N., "Automatizacija identifikacije otkaza rotirajucih mašina analizom mehanickih vibracija", doktorska disertacija, Fakultet Tehničkih Nauka Univerziteta u Novom Sadu, 2010.

[2.] Dr Licen Hotimir et all: "Continuous remote monitoring of vital parameters of mobile machinery relevant for their operating condition as a part of their total reliability and predictive maintenance" - Project 14037 financed by the Serbian Ministry of Science and Technological Development of Republic of Serbia, 2008-2010

[3.] James Taylor, Wyndell Kirkland: The Bearing Analysis Handbook: A Practical Guide for Solving Vibration Problems in Bearings: Vibration Consultants, 2004. ISBN 0-9640517-3-7

[4.] Zuber N., Ličen H.: Savremene metode praćenja stanja ležajeva na bazi merenja i analize mehaničkih vibracija, Održavanje mašina i opreme, 2006.

[5.] Zuber N, Licen H., Bajric R.: An innovative approach to the condition monitoring of excavators in open pits mines, Technics technologies education managment, Volume 5, number 1, 2010, pp 3-10, ISSN 1840-1503

[6.] Mobius Institute Vibration training manual – category III

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

APPLICATION OF VIBRODIAGNOSTIC IN TESTING OFF-ROAD VEHICLES

Aleksandar Đurić[1], *Snežana Jovanović*[2]

[1] Ministry of defence, Technical test center, Serbia, aleksandar_djrc@yahoo.com
[2] Ministry of defence, Technical test center, Serbia, sneza.jovanovic.toc@gmail.com

Abstract *- Vibrations are quite common appearance in mechanic.*

Vibrations in off-road vehicles are moustly present in suspension system. New technique in vibratins analysis, allow us to use vibration analysis in failure determination in off-road vehicle testing and maintenance.

The basic advantage is non-destructive work, with early prediction of failure in vehicles.

1. INTRODUCTION

Maintenance is the proces that follows the machine from it beginning (at the table of a constructor) to the end of it life time. There are four maintenance tipes:

- Breakdown maintenance – practise of allowing machine to fail rather than taking any preemptive action; it is still common to some extend in many plants today.
- Preventive maintenence – we will perform maintenance before the machine needs it, thus avoiding failure and extending its life; we need to estimate the life of a machine and then perform the overhaul just before it fails.
- Predictive maintenance – the philosophy about this is, that we do not fix and tuch the machine if it ain`t broke; we only monitor machines for the signs of failure, and then, when observed, the required maintenance is planned before the risk of failure is too high.
- Precision maintenance – we seek for the reason of failure, and then we are solving it in scheduled repair.

In vehicle testing, we are making some similar actions in failure prediction, and in giving a proper couse about what was the reason of failure. We are seeking for the early signs of faults and solve the problem before it makes more damages (in the early stages of faults and damage).

Testing of a quality of prototipes of off-road vehisles is using some maintenance tools for it purposes. All the time, the methodology of testing is being improved, so we can practise new technologies and new approaches. The methodology itselfe is involving tracking and analysing of specific number of direct and indirect values, that are being used like a indicator of working conditions in real exploitation terms for vehicle testing.

There are a number of different actions what we can do in gear transmission failure prediction:

- Oil temperature measurement,
- Wear particle analysis.
- Oil analysis.
- Bearing temperature measurement with IR camera.
- Vibration analysis...

Oil temperature measurement is very comon activity in vehicle gear transmission testing. Maximal oil temperature must be lower than about 120^0 C, moustly becouse of bearings. Oil temperature is being made in whole vehicle testing time, at a specific sample rate (time samples, km). We make a form of data base of oil temperature in vehicle gearboks during the testing, and we can form some assumptions about gearboks transmission level of damage.

Tipical routine oil analysis is made in time. We are following the particle enlargement and a inlargement of number of particles in oil semples. We are making a data base of oil analysis results, so we can asume that something is wrong with vehicle transmission gearboks.

Wear particle analysis often provides a wasrning of gear damage well before vibration analysis does. Cuting wear, abrasive wear, and sliding wear produce particles that are larger than the capabilities of spectrioscopy.

IR camera will provide us a record of bearings of vehicle transmission gearboks. That is important for early prediction of future failure of bearings and transmission.

Vibration analysis is important and more and more spread method for aumprion of gear failures in general (and in vehicle gears too). Forces within some machine cause vibration which is transferred to bearings. The forces are the result of rotational and fractional forces. With technology improvement in measurement and transducer equipment we have the posibility to ``see`` and ``hear`` vibrations in machines in general.

2. VIBRATIONS AND GEARBOX TRANSMISSION

2.1. Basic about vibrations

Vibration analysis study the vibration data to learn if any fault conditions are developing (what is important in vehicletesting, for early prediction of failures and more significant for rooth cause analysis of problem).

Vibration analysis method is making corelation between dominant frequentions and mechanical failure that one couse. The method itselfe is non-destructive, what makes it more proper for using in vehicle transmission testing. The researched vibartions are not pure forced as a consecvense of dinamic forces, but combination of forces and natural and resonant modal vibrations. Being generated from individual sorses, the measured vibrations signal at characteristics measurement place is superpozicija several elementary vibrations of different amplitude and frequency.

Vibrations in vibration analysis are defined with followin parameters:

- Amplitude (expresed like ``peak``level, or ``peak-to-peak`` level, or RMS level).
- Frequency.
- Phase
- Wave.

The main object for analysis is the time waveform, the electrical signal from the sensor. It represent vibration that we can measure in time measurement. This is the only real record of vibrations, and it is a source for all other vibration analysis tools.

Important part of vibrations is frequency. It is a reciprocal of time. Some event, who is periodical in time is repeatint itselfe in periodic time periods. Frequency in orders is frequency in RPM divided by the turning speed of the machine, or in gearbox the proper shaft.

Period of vibrations is duration of one cicle. Period is:

$$T = \frac{1}{f} \tag{1}$$

Where

f – frequency.

Peak value of a signal is the maximum excursion in one direction from the zero point (dhe actual value can be displacement, velocity or acceleration, or could simply be expressed as a voltage). In spectrum, peak is simply a sharp maximum:

$$a_{peak} = \max_T \left| a(t) \right| \tag{2}$$

Where

a(t) – measured or filtered acceleration,

T – integration time or measurement time.

Peak-to-peak is the level of a signal wave form, that is a difference bettween the highest positive peak level and the lowest negative peak value (often used for displacement measurement).

RMS (root mean square) is measure of level of signal. It is calculated by squaring the instantaneous value of the signal, averaging the squared values over time, and taking the square root of the average value. RMS value is the value which is used to calculate the energy or power in a signal :

$$a_w = \sqrt{\frac{1}{T}\int_0^T a_W(t)dt}\ , \tag{3}$$

Where

a_w –measured acceleration,

T–time of integration or measurement time.

All this components are founded in one vibration signal in time domain.

In measured time domen, is wery hard to recognise parts of individual vibrations generators, so, with apprishiasion of apsolute corelation of time and frequent domen, the measured and recorded signal is being analysed in frequent domain.

Spectrum is the result of transforming a signal from the time domain to the frequency domain. Spectrum analysis is the procedure of doing the transformation, and it is ofthen done with an FFT analyser. FFT analyser is vibration analysis tool that uses the Fast Fourier Transformation to display vibration frequency components. It is an algorithm (digital or analog routine used in FFT analyser) which calculates a spectrum from a time wave form. The basic of FFT is Fourier order:

$$x_{(t)} = \frac{a_0}{2} + (a_n \cos 2\pi n f_1 t + b_n \sin 2\pi n f_1 t) \tag{4}$$

Where

nf_1 – whole number product of basic frequency, harmonics.

The practical advantage of frequent spectrum is detection and determination of integral parts of sistem, what allows us to see problem in machine.

Frequency spectrum component can be divided in:

- Low frequency components domain – up to 500 Hz;
- Medium frequency domain – from 500 Hz to 2000 Hz;
- High frequency domain – higher than 2000 Hz

Gear vibrations are in most cases in medium frequency range.

For gerarbox vibration measurement we use high-sofisticated measurement equipment, with following software solutions for measurement and vibration anlysing. That allows us direct and postproces visualization oall things from load in extreme vehicle test conditions.In testing we are traing to be as much as posible sloas real exploitation conditions, so the values that we get in testing can give us objective picture about quality of tested vehicle.

2.2. Gears and some characteristic vibrations

Gearboxes have some specific frequencies and depending on the configuration may b edifficult to analyse. There are a number of reasons a gerabox may fail:

- Tooth wear.
- Tooth load.
- Backlash.
- Gear eccentricity.
- Gear misalignment.
- Broken / cracked teeth...

There are three frequencies involved in gearboxes, the frequency of gearmesh (number of teeth multiplied by the speed of the shaft), input speed and output speed:

- Gearmesh=Number of teeth x shaft speed.
- Output speed=Input speed x Input teeth/output teets.

Most faults are detected by studyng gearmesh frequency and second and third order of gearmesh frequencies along with their sidebands. A partial list of faults than can be detected through study is:

- Tooth wear;
- Tooth load;
- Gear eccentricity;
- Backlash;
- Gear misalignment;
- Broken or cracked teeth.

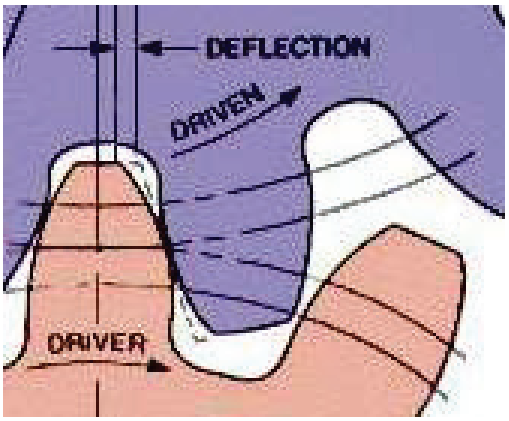


Fig. 1 *Conjunction of two gears in gearbox*

Vibration measurement conditions in real exploitation working conditions are non-stacionar nature (number of RPM≠const). Number of output engine shaft is variable in time and RPM is not const (it depend of driving conditions, gear level in gearbox etc.).

Vibrations itselfe are sinchronious with RPM of rotating mass. In spectrum posted sinchrone component are being generated – harmonics from cinematic frequencies (made order).

Relation between RPM and order frequency is**:**

$$OrderN(Hz) = N \times {RPM}/{60} \tag{5}$$

I-order is ratio of RPM and 60, and N-order is multiplication of I-order and integer.

Basic order is I-order. But, in gears, basic vibrations are consequence of RPM and gear-wheels. I-order of shaft is one characteristic for gearbox. Second characteristic order is I-order multiplicities with m (m-module of gear-wheel). That is I-order for gear in conjunction.

Potential cause of spec ific aditional vibrations can be tooth wear/load, eccentricity of gear, backlash, damaged gears... in vehicle gearbox.

Defect gears generate high and medium frequency vibration, which are suitable to multiplication of defect gear tooth number (r) and RPM of drive gear (n). Signal form from defect gear toot can be recognized:

$$f_{toothing} = f_{shaft} \times N_{tooth} \tag{6}$$

Variable vibrations are occurring in gear-wheels that work under low load, because loading is advancing from one tooth in conjunction to another. Beside characteristic frequencies coupled to basic number of revolutions of rotating elements, in spectrum there are also frequencies combined with structural, resonant system characteristics, frequencies from second gear conjunction, frequencies characteristic for bearings... Impacts, which are results of load changing, can excite gear natural frequency. Frequency analysis has important part in failure prediction at gearbox, and gives us a non-destructive tool for determine time of maintenance in transmission elements.

Gear vibrations can be defined like a form of free damped vibartions, which are being excited with everi new conjunction ot two teeth. With that aproximation, we can make analitical model for determing vibrational levels.

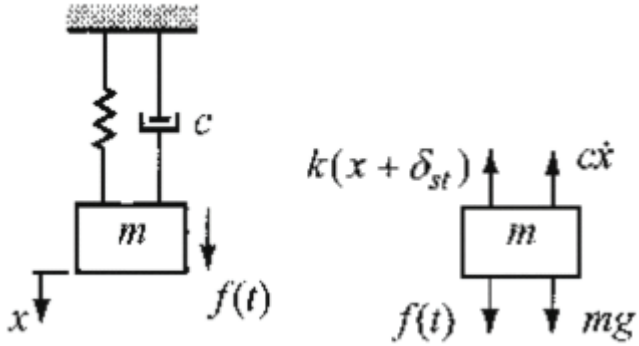


Fig. 2 *One degree of freedom model*

The fundamental physical law governing all vibration phenomena is Newton's second law, which in its most commonly used form says that *the sum of the forces acting upon an object is equal to its mass times its acceleration.* Force and acceleration are both vectors, so Newton's second law, written in its general form, yields a vector equation. For the one degree of freedom (DOF) system, this reduces to a scalar equation, as follows:

$$F = ma \tag{7}$$

Where:

F – Sum of forces acting upon body;
m – Mass of body;
a – body acceleration.

For the system in Figure 2, equation (7) yields its differential equation of motion, as follows:

$$m\ddot{x} + c\dot{x} + kx = f(t) \tag{8}$$

The solution for the motion of the unforced one degree of freedom system is important in its own right but specifically important in laying the groundwork to study self excited instability rotor vibrations. If the system is considered to be unforced, then $f_{(t)}=0$ and equation (8) becomes the following:

$$m\ddot{x} + c\dot{x} + kx = 0 \tag{9}$$

This is a second order homogeneous ordinary differential equation. To solve for $x_{(t)}$, from Equation (9), one needs to specify the two initial conditions, $x_{(0)}$ and $\dot{x}_{(0)}$. As summing k and c are both positive, three categories of solution can result from equation (3), (a) under damped, (b) critically damped, and (c) over damped. These are just the traditional labels used to describe the three distinct types of roots and the corresponding three motion categories that equation (3) can potentially yield when k and c are both positive.

Substituting the known solution form ($Ce^{\lambda t}$) into equation (3) and then cancelling out the solution form yield the following quadratic equation for its roots (Eigen values) and leads to the equation for the extracted two roots, $\lambda_{1,2}$, as follows:

$$m\lambda^2 + c\lambda + k = 0 \tag{10}$$

$$\lambda_{1,2} = -\frac{c}{2m} \pm \sqrt{(\frac{c}{2m})^2 - (\frac{k}{m})} \tag{11}$$

The three categories of root types possible from equation (4) are listed as follows [3]:

1. Under damped, $(\frac{c}{2m})^2 < (\frac{k}{m})$, complex conjugate roots, $\lambda_{1,2} = \alpha \pm i\omega_d$;
2. Critically damped, $(\frac{c}{2m})^2 = (\frac{k}{m})$, equal real roots, $\lambda_{1,2} = \alpha$;
3. Over damped, $(\frac{c}{2m})^2 > (\frac{k}{m})$, real roots, $\lambda_{1,2} = \alpha \pm \beta$.

But, only in risent time, with usage of computer equipment in higher scale, complex analitycal models can be solwed for relative short time of period.

Cepstrum analysis is a tool for the detection of periodicity in a frequency spectrum, and seems so far to have been used mainly in speech analysis for voice pitch determination and related questions. In that case the periodicity in the spectrum is given by the many harmonics of the fundamental voice frequency, but another form of periodicity can also be detected by cepstrum analysis is the presence of sidebands spaced at equal intervals around one or a number of carrier frequencies. The presence of such sidebands is of interest in the analysis of gearbox vibration signals, since a number of faults tend to cause modulation of the vibration pattern resulting from tooth meshing, and this modulation (either amplitude or frequency modulation) gives rise to sidebands in the frequency spectrum. The sidebands are grouped around the tooth-meshing frequency and its harmonics, spaced at multiples of the modulating frequencies, and determination of these modulation frequencies can be very useful in diagnosis of the fault.

The cepstrum exist in various forms but all can be considered as a spectrum of a logarithmic (amplitude) spectrum. This means that it can be used for detection of any periodic structure in spectrum, e.g. from harmonic, sidebands, or the effects of echoes. It is also shown, however, that effects which are convolved in the time signal (multiplied in the spectrum) become additive in the spectrum, and subtraction there results in a deconvolution. Using the function terminology to indicate the forward Fourier transform of the bracketed quantity, the original definition of the cepstrum is:

$$c_{(t)} = \left| F\{\log F_{xx}(f)\} \right|^2 \tag{10}$$

2.3. Evaluation criteria

Following standards are made based on level of various number of vatching and integrating practical expirience, so they can`t fully cover real sistems. Criteria are not allwaus applicable. The ISO standards are giving thresh holds, like manufacturer lists and expirience values..

Some standards for gear vibartion levels are: ANSI/AGMA 6000-B96 i ISO 8579-2.

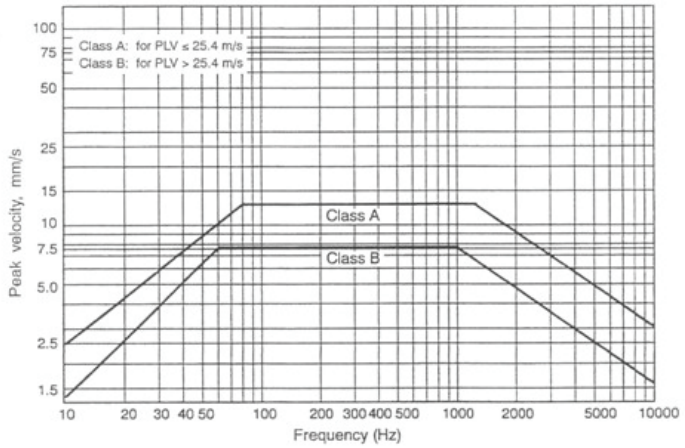


Fig. 3 *Velocityvibration level (peak valuein mm/s) of gears according to ANSI / AGMA 6000-B96*

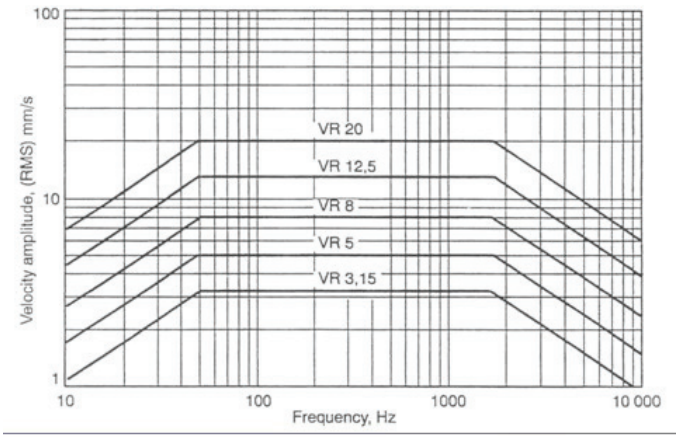


Fig. 4 *Vibration velociti (peak value in mm/s) of gears according toISO 85792-2*

3. VIBARTION MEASUREMENT IN REAL CONDITION

The vibration diagnosis and analysis is following steps:

- Analysis dynamic system, which is the object of measurement.
- Preparation for measurement.
- Vibration measurement and number of revolutions.
- Analysis of measured vibration signal (frequency and harmonic).
- Diagnostic conclusion.

Measurement object was gear set of vehicle, which is a prototype (off-road vehicle with regular and non planetary gearbox). All measurements have been made in mountain off-road conditions, in every gear. For measurement we used

four acceleration transducers, CTC–131 type. There was four points for measurement. Precise measurement points were:

- Two points in input shaft (transducers 1 and 3), in place of input bearing.
- Two in output shaft (transducers 2 and 4), in place of output bearing.

Multi channel measurement, type NETdB 12, French manufacturer 01 dB Metravib, Areva Corporation. Measurement equipment is set with software also from 01-dB Metravib, Areva Corporation. Measurement place for transducers were bearing boxes of input and output shift. Measurement set signal was recorded to PC hard-disk (laptop), for future analysis. All measurements are being made at about 2000 rpm of vehicle engine, with calculation of transmission ratio.

In the beginning, nought state was measured, for determing starting parameters for measurement. After, only periodically measurements are being made (at about every 2000 km). Next parameters were measured:

- Absolute vibrations with four accelerometers in measurement points.
- RPM with laser tachometer.

With post-process mathematic averaging we are processing random time signal, which we recorded in measurement of working load characteristics (vibration and number of revolutions) in off-road conditions drive. After all measurements, we made vibration analysis, which include:

- Time signal filtration.
- Recorded acceleration signal integration.
- FFT (Fast Fourier Transformation) transformation.
- Mathematic parameter selection (RMS, log) for presenting 2D I 3D (Waterfall) spectrum for analysis.
- Cepstrum analysis.

For gear vibration signal, magnitude modulation is characteristic, as a result of excenter and frequency modulation appearance, which cause variation of some gear wheel rpm. There are several characteristics for gear vibrations:

- Frequencies from errors in making gears, that are nonsensitive to load alteration.
- Sidebands from magnitude (tooth conjuction deformation) and frequency (rpm fluctuation) modulation.
- Low harmonics from extra impacts, at every rpm.
- Combination of frequency components of conjunction.

For this measurement we used laser tacho probe too, made by Monarch instruments, attached to gearbox output shaft. From numerous measurements we made, in paper we'll present spectrum for second gear in different off-road conditions, for transducer 4.

All measurements were made in real off-road conditions, in different off-road types. We made measureemnts in off-road conditions at road at mountain Fruska gora. All the measurements were made in uphill driving.

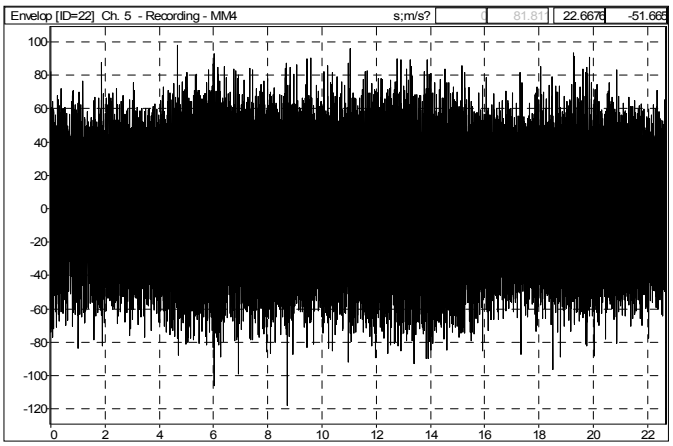


Fig. 5 *Speed signal in time for second gear,(m/s2 / s)*

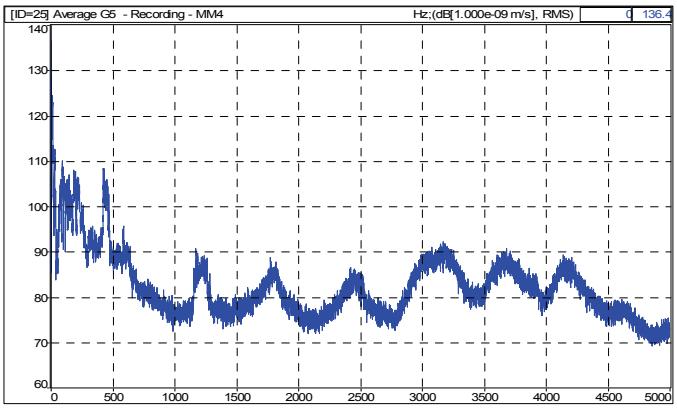


Fig. 6 *Frequency spectrum, (dB/Hz)*

Frequency spectrum is giving us the levels of vibrations, picks and frequencies that are characteristic for some pick values. In frequency spectrum we can identify frequencies from output shaft, conjucted gears, gear mesh frequency and found some frequencies that are not expect to see in that signal.

Characteristic frequencies are:

- 6,4 Hz, frequency of the I-order of the output shaft (RPM of the output shaft is at about 386 rpm/60= 6,4 Hz).
- 15,4 Hz, gear mesh frequency of the output shaft and conjugated gears. All subharmonics we can get by multiplication of the first order.
- 554 Hz, the I-order of the conjugate output gear.
- Other subharmonics we can get by multiplication of the first order of output shaft frequency and gear mode.

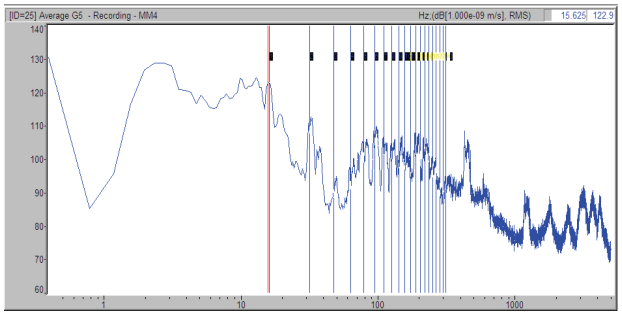


Fig. 7 *Logarithm of the frequency spectrum, specific frequencies (dB / Hz)*

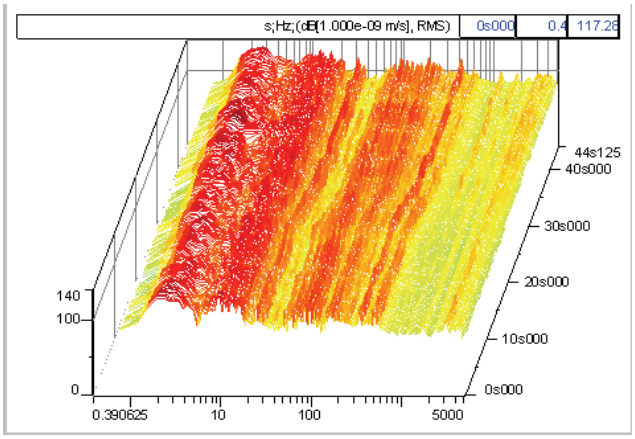


Fig. 8 *3D spectrums for second gear (dB / Hz / s)*

In 3d spectrum diagram we can see specific frequencies, in multispectrum conditions. Time, frequency and pick levels are shown in one diagram.

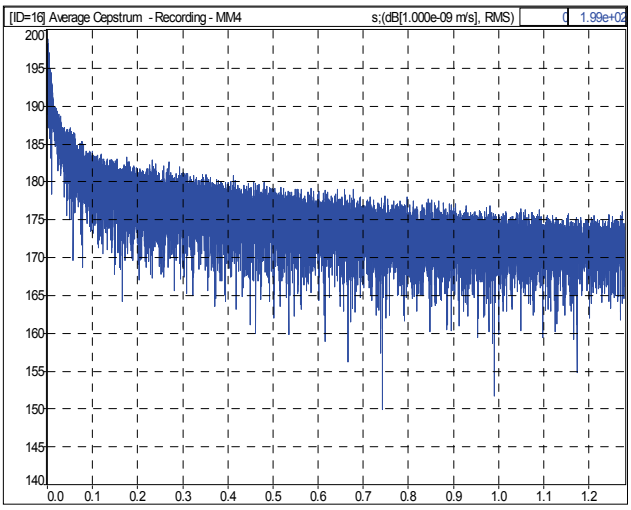


Fig. 9 *Cepstrum of recorded signal (dB / s)*

Cepstrum of the signal of vibration measured in second gear of transmission at Fruska gora off-road conditions is shown in figure 9. The main advantage of cepstum is, because he's finding all periodic events (it is shown as diagram pick at some time). In this signal there was no characteristics picks at any time. In this signal we can see that there is no pick values that would made some suspicion that something is at (or will be in short time period) failure. The conclusion was that in that gear there is no specific problem with gears in second gear.

CONCLUSIONS

In our signals in second gear, that we recorded during vehicle testing in off-road conditions we found no characteristics picks at any time. Main conclusion was that gear set is working without damages or failures that are going too happened. At the end of testing, we opened gear set and explore all gears in gear set of vehicle transmission. We didn't found out any failure. That gave our conclusions a form of evaluation.

Cepstum tool for vibration analysis is finding all periodic events and showing it at diagram, like a pick at some time. It is wary suitable for non aggressive gear testing and condition analysis in real working conditions of vehicle transmission.

Usage of cepstrum analysis in vibration analysis of vehicle gear transmission testing in validation and estimation of vorking conditions and failures (future failures) is a relative new approach in vehicle testing. With respect to it non damage nature, in future time it`s going to be more exploit tool in vehicle testing, and maintenance and monitoring of working condition in vehicle work time period. We can detect weak spots in early phase, without dismantling of transmission. All the testing we can make faster and more economic.

REFERENCES

[1] Mobius Institute, "Vibration training course, category II", ch. 1, 2, 19, September 2012.

[2] A. Djuric, S. Jovanovic, "Cepstrum analysis of vibration in transmission system of the vehicle", International conference "MVM2012" Kragujevac.

[3] A. Djuric, S. Jovanovic, "Vehicle transmission examination with use vibration analysis", International conference "MVM2010" Kragujevac.

[4] Zuber N., Licen H., "An innovative approach to the conditionmonitoring of excavators in open pits mines", Technics technologies education menagement 2010.

[5] Todorovic J., "Examination of vehicles", Belgrade 1979., page 223.

[6] Denikin M.D., Sokolova A.G., "Vibro-acoustic diagnostics of machines and mechanisms", Mechanical engineering, 1987., page 35.

[7] Batinic V., "Determination of gear mesh stiffness in planetary gearing", Military technical courier 2/2008.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

Use of Conformal Mapping Method for Visualization and Classification of Acoustic Signals

Tihomir Trifonov[1], Georgi Dimkov[2], Ivan Simeonov[3], Rosen Dzhakov[4]

[1,3,4] “Vassil Levski” National Militery University, Dept. IC Systems,
TihomirTrifonov@ieee.org, ivan.simeon@gmail.com, rosen_djakov@abv.bg
[2] Bulgarian Academy of Sciences, Dept. Complex Analysis, gdimkov@math.bas.bg

Abstract - *New method for visualization and classification of acoustic signals is proposed. It is based on well known in mathematics conformal mapping. Mathematical foundations of the method in connection with the spectral and wavelet analyses are described. Specific practical applications are obtained and some specific techniques for visualization are proposed. The best platform for collecting and processing of acoustic, seismic, underwater acoustic and other signals in real time “PULSE”, Bruel&Kjaer, is used. The notion of “sound print” of an object is introduced and discussed.*

1. INTRODUCTION

In the present paper we record and analyze the sound of church bell, pistol shot and thunder. The frequency and dynamic ranges of all three sound sources are very large. The spectrum of their basic sound contains infrasound, sound and ultrasound components (e.g. [1]). The dynamic range exceeds the human hearing harmless limit of 120 dB. These characteristics require the use of special microphones and measuring and analyzing equipment. The solution of this problem was the use of one of the world best system PULSE – Brüel&Kjær [2].

A very powerful instrument for studying the specific characteristics of the signals are the spectral and wavelet analysis. Producing spectrograms and scalograms they enable the visualization of the characteristics of the sound under investigation.

In the sequel, using conformal mappings, we introduce the “sound print” as a better and easier possibility for the different acoustic analyses.

2. CONFORMAL MAPPINGS – A SKETCH

Let $w = f(z)$ be a complex valued function of complex variables. If $f'(z_0) \neq 0$, than

- (i) in some neighborhood of z_0 the function $f(z)$ is univalent, i.e.

$$f(z_1) = f(z_2) \Rightarrow z_1 = z_2;$$

- (ii) the function preserves the angles between curves intersecting in the point z_0, i.e. there the mapping realized by $f(z)$ is conformal.

The exponential function $w = e^z$ is the most interesting function from analytic and geometric point of view:

- (i) e^z is defined and different from zero for each $z \neq \infty$;
- (ii) $(e^z)' = e^z \neq 0$ for each $z \neq \infty$; (cf. above remark for univalence);
- (iii) $e^z = e^{x+iy} = e^x \cdot e^{iy}$ shows that:
- (a) lines parallel to the abscise, mapped by e^z become rays starting from the origin;
- (b) lines parallel to ordinate axis, mapped by e^z become circles centered at the origin;
- (c) the exponential function is periodic with basic period $2\pi i$.

The last property says that the exponential function is univalent, in the above described sense, in each horizontal strip with (vertical) width 2π.

Let $-\infty < a < b < +\infty$ Now consider a rectangle with vertices (in counterclockwise direction) a, b, $b+2\pi i$ and $a+2\pi i$. The image of this rectangle, mapped by e^z, is a concentric ring centered at the origin with radii and e^a and e^b respectively [3].

3. SPECTROGRAMS, SCALOGRAMS AND SOUND PRINTS

3.1. Spectrograms and scalograms

Spectrograms and scalograms are obtained using Pulse [2] with appropiate software as well as MatLab&Simulink [4].

3.2. The sound prints

The usual scalogram has the form of a strip. After appropriate changes of the position and its dimentions the scalogram we transform it by the exponential function onto a concentric ring [5]. As analog of the “fingerprint”, used in the criminology we called this new shape „sound print”.

3.3. Practical results

As we mentioned earlier we analyzed records of three sound sorces.

3.3.1. Church bell

The bell under examination is situated in a church in the city of Veliko Turnovo, Bulgaria. More could be found in [6, 7]. Figures 1. up to 4. present the record, spectrogram, scalogram and sound print of the sound.

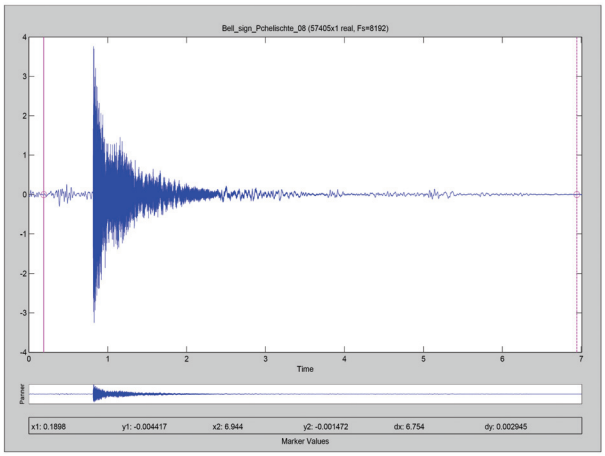


Fig. 1. *Record of the bell stroke*

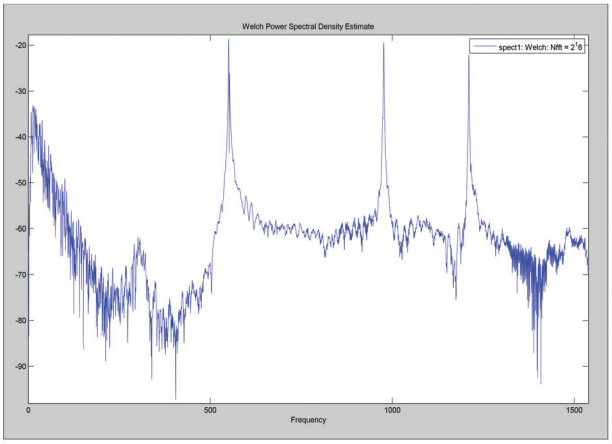


Fig. 2. *Spectrogram of the bell stroke*

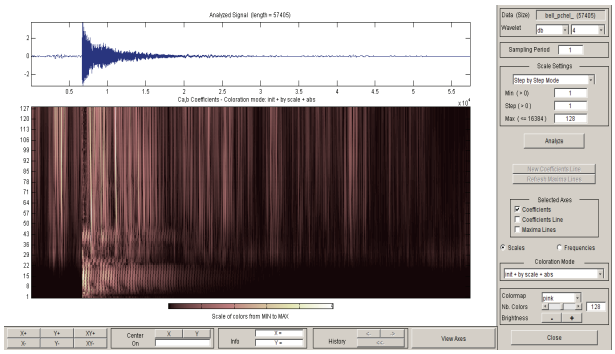


Fig. 3. *Scalogram by means of Continuous Wavelet Transform*

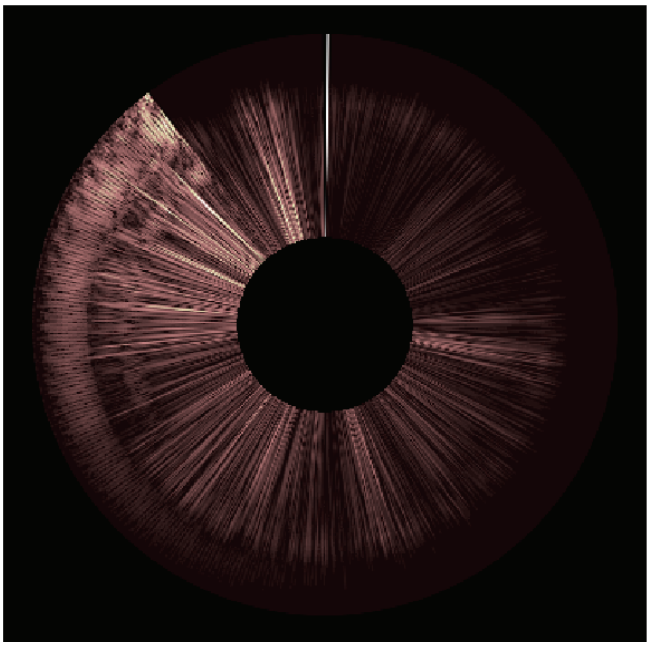


Fig. 4. *Sound print of the bell*

3.3.2. Pistol shot

Next four pictures show te examination of a pistol shot.

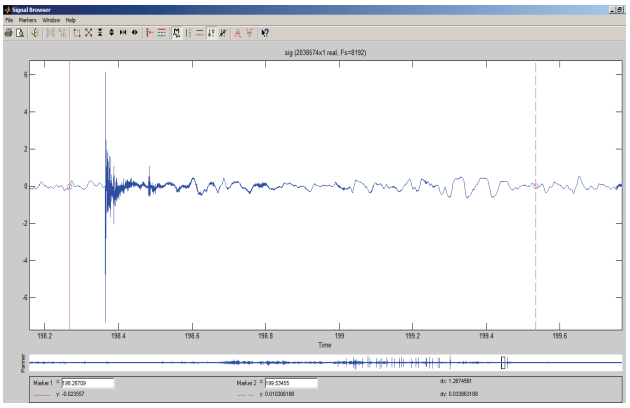


Fig.5.*Record of the pistol shot.*

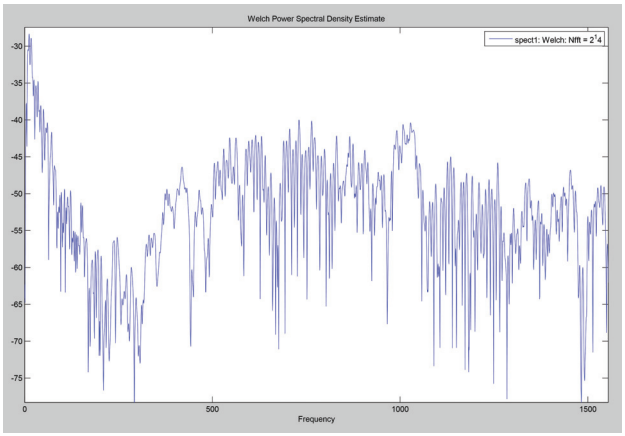


Fig.6. *Spectrogram of the pistol shot.*

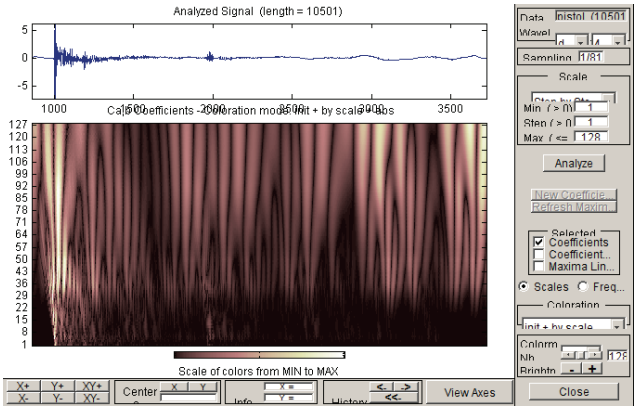


Fig.7. *Scalogram of the pistol shot.*

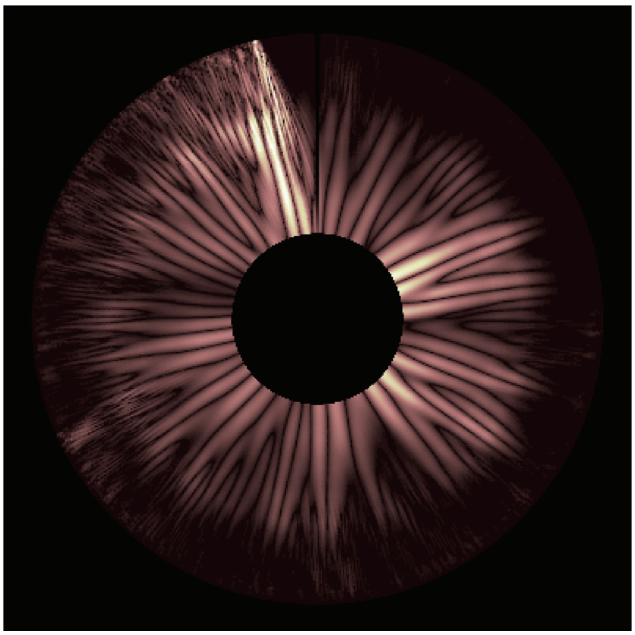


Fig.8. *Sound print of the pistol shot.*

3.3.3. Sound of a thunder

Examination of the sound of a thunder

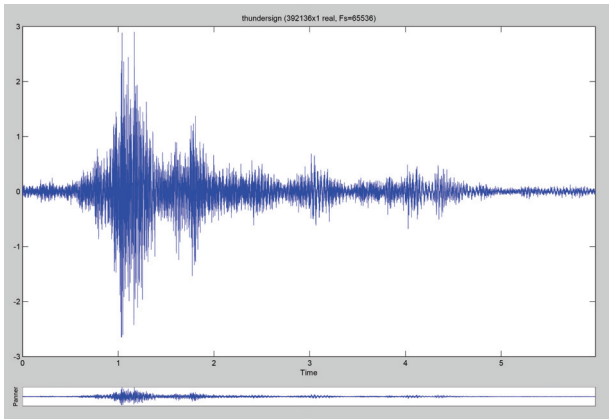


Fig.9. *Record of a thunder*

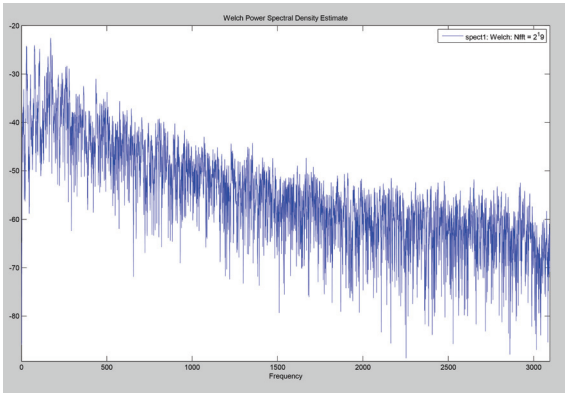


Fig.10. *Spectrogram of a thunder*

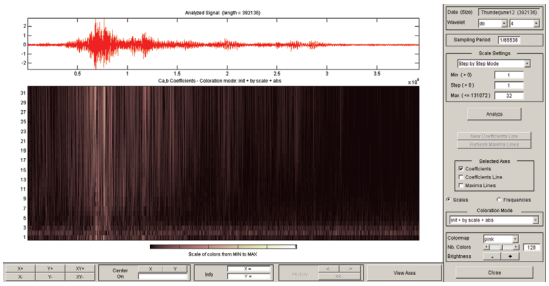


Fig.11. *Scalogram of a thunder*

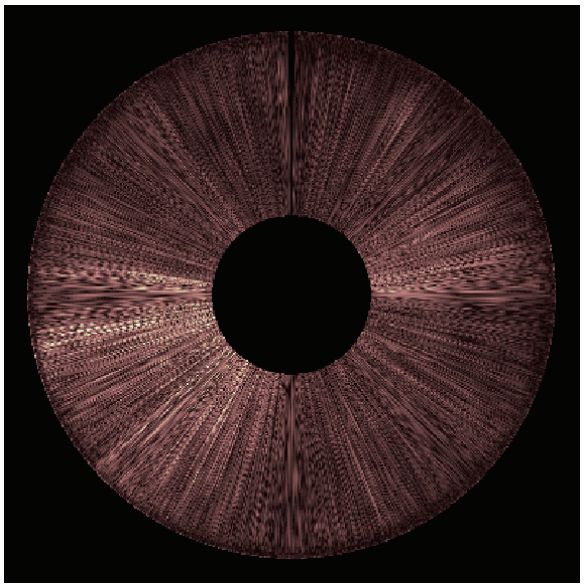


Fig.12. *Sound print of a thunder*

4. DISCUSSION OF THE RESULTS AND CONCLUSION

It is worth to remark that the conformal image of the scalogram gives better visualization of the special features of the acoustic signal. It is seen that by three different sources with large dynamic range and frequency spectrum the enerfy of the thunder produces infrasound waves, the particals of the bell are good dicsernable. It is possible to identify the muzzle wave of the shot.

Sound prints of different sound sources could be collected to create a library similar to the fingerprint libraries which will facilitate the recognition of the unknown records.

It is an attractive idea to use the methods of the good developed eye iris recognition.

REFERENCES

[1] BELL: Research and Identification of Valuable Bells of the Historic and Culture Heritage of Bulgaria and Development of Audio and Video Archive with Advanced Technologies), KIN-1009, Institute of Mathematics and Informatics, Bulgarian Academy of Sciences , (http://www.math.bas.bg/bells)

[2] Brüe&Kjar, www.bksv.com

[3] Lars Ahlfors, An Introduction to the Theory of Analytic Functions of One Complex Variable, New York, 1953.

[4] MathWorks, www.mathworks.com

[5] Alexander D. Poularikas, *The Transforms and Applications Handbook*, Second Edition, CRC Press, 1999

[6] G. Dimkov, Al. Aleksiev, I. Simeonov, T. Trifonov, K. Simeonov, Acoustical researches on historical valuable Bulgarian bells, In Proceedings of the National Scientific Conference on Acoustics, Sofia, Bulgaria, 2008, pp. 115-124 (in Bulgarian).

[7] Tihomir Trifonov, Georgi Dimkov, Rosen Dzhakov, Ivan Simeonov, Research and identification of valuable bells of the national historic and cultural heritage of Bulgaria, In Proceedings of the XXII Conference with International Participation "Noise and Vibration", Nish, Serbia, 2010, pages 103-107.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

NOISE CONTROL OF INTEGRATED REFRIGERATOR AND FREEZER DOMESTIC APPLIANCE

Nikola Holeček[1]

[1] Gorenje d.d., Environmental Protection College Velenje, Slovenia, nikola.holecek@gorenje.si

Abstract - *In addition to highly complex functional features and low energy consumption the silent operation of a domestic appliance is an essential design component of a modern integrated refrigerator and freezer. This is because noise emission is an extremely important differentiating factor when choosing a new appliance; therefore, manufacturers of exceptionally silent appliances usually advertise their low noise emission using terms such as "super silent operation". This article presents a procedure to obtain the desired noise level for such an appliance. All measurements were conducted in an acoustics laboratory, under free-sound-field conditions. The level of noise in the different development phases was represented by the total sound-power level, the frequency spectrum and using sound imagining analysis. Based on our results we determined the critical sources of internal noise and from this were able to make the necessary design modifications necessary to reduce the sound-power level from 57.6 dB (A) to an acceptable 44.5 dB (A).*

1. INTRODUCTION

To meet the needs of the most demanding appliance markets, large built-in Integrated Refrigerator and Freezer (IRF) units with a width of 0.75 m, height of 2 m and weighing over 230 kg have been developed (Figure 1). Considering the size and weight of the appliance, all the vital parts of the refrigeration system's components i.e., the compressor compartment containing two compressors, a dynamic condenser and either one or two fans are located in a pull-out drawer at the bottom of the appliance accessible from the front side, so that they can be readily accessed without having to move the appliance (Figure 1 & 2).

The upper compartment of the appliance is intended for refrigeration (fresh food, FF), the middle compartment is a freezer (bottom freezer BF) with an automatic ice maker, while the bottom compartment is a multifunctional drawer (convertible drawer, CD), which can be used either as a freezer, a refrigerator or a wine storage unit. Such a wide range of functions requires a working temperature of -21.1 to +12.8 °C and in order to achieve this, an innovative cooling system was developed.

The appliance's features control the thermal loads within the unit by varying the cooling volume flow by means of hatches, fans and by varying the cooling power of the compressors. For the purpose of cooling two separately adjustable compartments, a multi-channel system is installed to distribute and inject air into the interior, ensuring a homogenous temperature field within the internal spaces. The majority of these design solutions were first verified by means of numeric simulations which, to some extent, provided the answers to the questions regarding how to ensure that an appropriate temperature field exists in each of the individual compartments.

Here we present our comments on selecting appropriate design concepts. A design with the lowest and continuous airflow velocity and acceleration should give the best results in terms of acoustic properties. Continuous operation in general produces less noise than intermittent operation. For the given operating mode, the noise of the appliance can be reduced by making the correct design choices. Materials, shape, position, number of elements, dimensions, structure and how these elements are connected can all have a significant impact on noise emissions and if chosen correctly can significantly reduce vibrations and sound propagation. In this paper we present a development procedure. This development procedure included noise measurements, data analysis and replacement of parts, representing important noise sources, leading to a significant reduction in acoustic emissions.

2. ANALYSIS OF NOISE SOURCES

In order to reduce noise emissions, we adopt a methodology of identifying and eliminating the critical sources of noise in the earliest possible stages of the design phase.

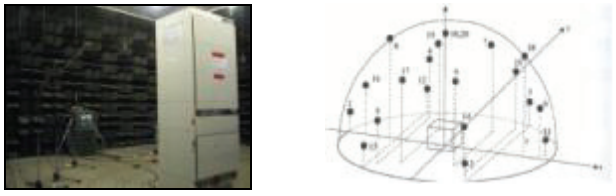


Fig. 1*: Measuring the noise emissions of the IRF prototype in a semi-anechoic chamber (left). Microphones were located at 20 points on the surface of a virtual hemisphere (right).*

The first step involves determining the main noise sources within the appliance and making a priority list or plan. Once the main sources have been determined, they need to be characterised and a more detailed analysis of the actual noise mechanisms conducted. The next step requires an analysis and a description of how noise propagates out from its source and how it is then transmitted through the structure onto propagation surfaces. This is then followed by an analysis of

how it propagates from these surfaces and then determining their contributions to the sound pressure level at inlet points. Finally, an estimate can be made of which combination of noise abatement measures is the optimal one, [1]. Using an appliance prototype, we have the opportunity to verify, with actual measurements, the operation of the actual appliance design (Figure 1).

The active components that generate noise in an IRF appliance are the following: the centrifugal fan in the FF-compartment, the axial propeller fan in the BF-compartment, and the axial fan and two compressors in the compressor compartment (Figure 2).

Fan noise depends on fan type: radial or axial, and on the operating conditions. If the impeller is well balanced and fixed in place to prevent any transmission of vibrations, then the generated noise changes in relation to the operating settings. Fans are usually designed such that they emit the least amount of noise at their optimal operational setting, while any deviation from this usually increases the amount of noise being generated. Volume flow rates below optimal induce vortices and flow separations that lead to an increase in pressure pulsations, which are then reflected as broadband noise at frequencies lower than the rotational frequency of the impeller. At volume flow rates above optimal, broadband noise is generated [2].



Fig. 2 *Elements of a compressor compartment (unit) – basic design: dynamic condenser (1), axial fan (2), two 'variable speed drive' (VSD) compressors (3), air inlet grille (4), air outlet grille (5)*

Yet another significant noise source are the stationary channels and the compressor compartment grille where it was not possible to achieve optimal flow conditions during the design process due to technical and spatial limitations. In places where the channel cross-section is either enlarged or diminished, flow separation or recirculation can occur, leading to pressure and flow velocity pulsations and to the generation of turbulent noise, [3].

3. METHODOLOGY DESCRIPTION

Reduction of noise generation in domestic appliances may only be achieved after sufficient data concerning noise sources and noise transfer routes is obtained. This information is also dependant on frequency interval. Source analysis can be performed based on the spectrum of radiated sound combined with knowledge of the potential internal noise sources, rotational speed, and the number of blades on the fan etc. Peaks in the emitted noise pressure spectra can be attributed to selected relevant noise sources.

In the case where information from emitted noise spectra does not bear information about the noise sources, the method of (reversed) elimination of noise sources is available. At every step, we determined the total energy flow (sound power) of the appliance and record the sound spectra, [4]. Partial contributions are also analyzed by means of visualizing the sound field i.e., creating a sound image, to establish the actual point from which a sound originates [5]. Although this can be viewed as a complex problem, it is feasible by using measurement techniques for noise source identification (NSI). In this study, we made measurements of the density of energy flow of sound waves (sound intensity) and used the NSL 7681 B&K (noise source location) program for sound imaging processing.

4. DESCRIPTION OF USED MEASUREMENT PROCEDURES

As mentioned in section 2, engineering methods were used in the process of noise reduction in the IRF appliance. We conducted measurements to determine both the sound power level and to visualize the sound field surrounding the unit.

4.1. Measurement of sound power level

Measurements of sound power level required an appropriate acoustic environment in the form of a free sound field which allows sound waves to propagate freely without reflections. For laboratory testing, we used a semi-anechoic chamber to ensure good repeatability and low measurement uncertainty. To provide a free sound field above the reflective surface, the testing chamber must:

- be of an appropriate size,
- have a high sound absorption capacity across the entire monitored frequency range,
- be without acoustically reflective surfaces and obstacles with the exception of the floor in a semi-anechoic chamber,
- have an adequately low level of background noise.

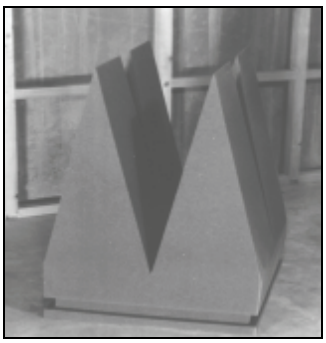


Fig. 3 *Absorption wedges*

Our semi anechoic chamber had a free-space volume of 220 m^3 (7.8 m x 6.7 m x 4.2 m). Its walls and ceiling are coated with sound-absorbing polyurethane foam wedges. The wedges are 80 cm long and a 5-cm air gap exists between the wedges and the walls (Helmholtz resonator). The total length of the wedges and the air gap was $\lambda/4$, where λ is the wavelength of the sound corresponding to the frequency centre of the lowest monitored frequency band, [6]. The shape and dimensions of the wedges (Figure 3) were determined based on the measurements in the Kundt tube. To prevent the absorption coefficient, which was at least 0.99,

from being dependent on the wave's angle of incidence, the wedges were installed mutually rotated by 90°. All measurements in the anechoic chamber were made according to ISO 3745 [7]. They reveal that the lower frequency limit is 100 Hz, the background A-weighted sound pressure level is 13 dB and the discrepancy from legality "1/R" is between 90 Hz to 10 kHz, which is admissible according to the standard [7].

All objects and measuring equipment, except sensors and microphones, were located outside the chamber. Hollow tubes for cable access were filled with sound absorbing material to prevent the transmission of vibrations.

To make source acoustic-power measurements according to the absolute method a measuring system was used, which consisted of 20 Falcon TM Range ½"-type 4189 (Brüel & Kjær) microphones and 20 Delta Tron-Type 2671 microphone pre-amplifiers. To determine the sound power level, we used the PULSE measuring system manufactured by B&K and for the analysis a standard multichannel real-time analyzer 3560D. Measuring the power level in the free sound field above the reflective surface in a semi-anechoic chamber was conducted in compliance with the requirements of the international standard EN ISO 3745:2003, [7]. The sound pressure level was measured simultaneously at 20 measuring points spirally distributed around a virtual hemisphere. The entire measuring procedure was conducted using the PULSE program with the installed application 7771 for sound power level measurement. The results were recorded and transferred *via* an ActiveX link into a standard Excel spreadsheet. All the measuring equipment was calibrated using a piston phone and a sound-intensity calibrator with a valid certificate of calibration. All measuring system elements, including microphones and cables, complied with Instrument Class 1 in accordance with IEC 61672-1:2002 [8]. The filters used also complied with Instrument Class 1 in accordance with IEC 61260:1995 [9].

4.2 Measurements of sound intensity

By measuring sound intensity, our aim was to visualize the density of the energy flow of the sound waves on all five sides of the IFR unit. To that purpose, we selected 86 measurement points. The measurement plane was 60 mm away from the appliance's surfaces. The measurements were conducted at discrete points in the near field of the whole unit. Afterwards we measured only the vector field of sound intensity at the front side of the compressor compartment, where most of the noise sources are located. Sound-intensity measurements of the IRF acoustic characteristics were performed using a two-channel analyzer with a sound-intensity probe placed at a discrete distance and using the Noise Source Location program. The purpose of this program is to help locate the source of the noise emitted from the IRF unit [10, 11]. The sound-intensity probe was positioned by a computer-controlled traversing system. Since the absolute precision of the Class I sound power measuring method had been used for the precise calculation of energy flow, we also used for visualisation i.e., sound imaging, which is the main advantage of this technique.

5. MEASUREMENT RESULTS

5.1 IRF unit during operation with different internal noise sources

To identify the noise originating from the compressors situated in the compressor compartment, we first measured the sound pressure level at a distance of 1 m from the compartment (Figure 5). However, it was later realized that a higher level of noise was being generated by the centrifugal fan located in the FF compartment. Figure 5 shows the frequency spectrum of the sound pressure on the front side of the compressor unit compartment (basic design). The peaks in the spectrum are the harmonics associated with the rotating frequency of the fan and the frequencies that are generated on the blades of the axial fan in the compressor compartment.

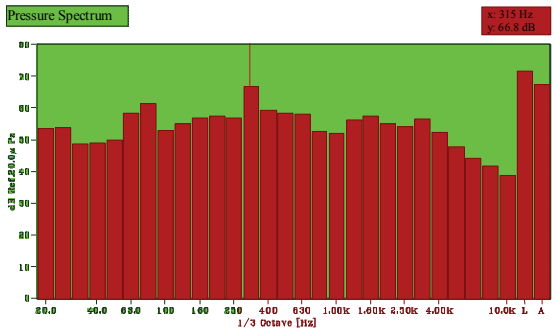


Fig. 5 *Frequency spectrum of the sound pressure of an IRF unit recorded for preliminary characterization of internal sound generators at 1 m in front of the compressor compartment*

In a follow-up, we conducted measurements of the total sound power level of the IRF unit under the following operating conditions:

a) only the propeller fan in the BF-unit,
b) only the cooling compressors,
c) only the axial fan in the compressor unit,
d) only the centrifugal fan in the FF-unit.

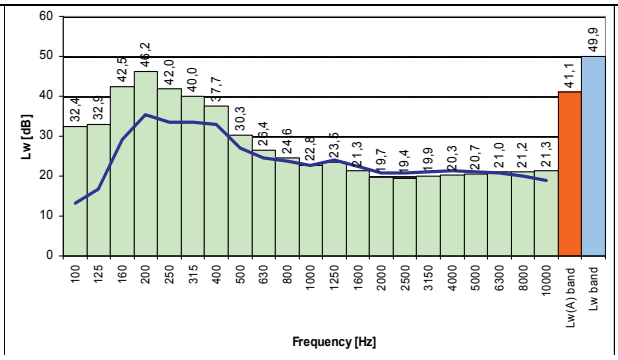
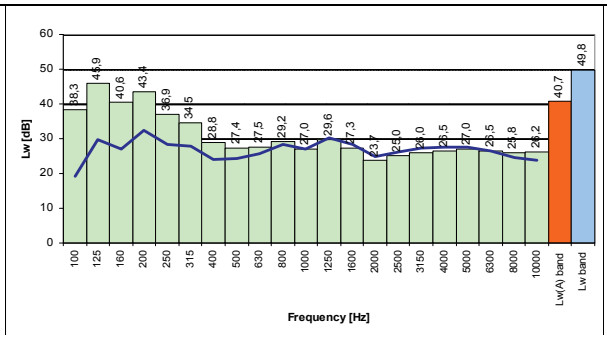
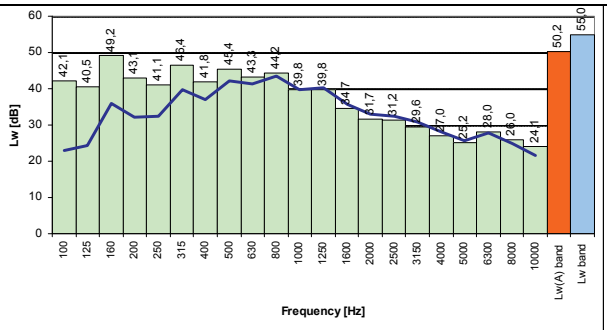
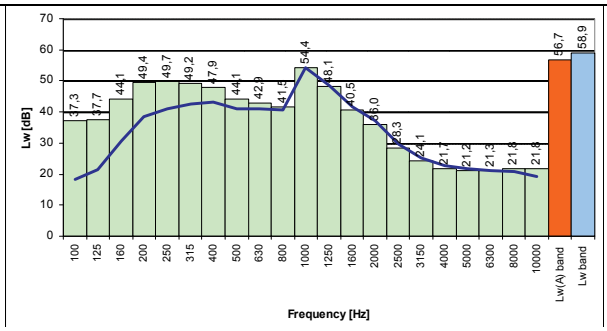
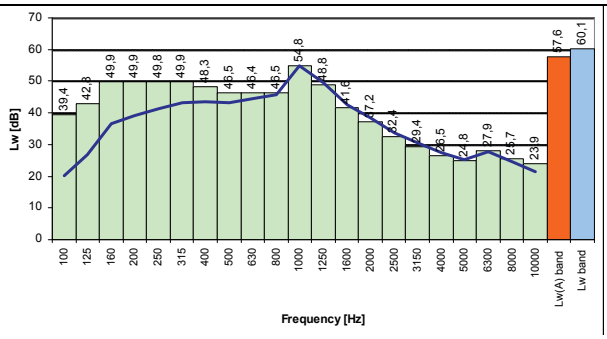
The results are shown in Table 1.

The results in Table 1 are presented as total sound-power level (A-weighted) together with the sound-power frequency spectra. Table 1 reveals the reasons for the increase in the IRF unit noise level. The fan operating in the BF unit (Table 1 - 5a) and the operation of both compressors (Table 1 - 5b) is not responsible for increased IRF unit noise level. Instead the dominant noise sources are (1) the centrifugal fan in FF compartment, that emits a sound-power level of 56.7 dBA (Table 1- 5d) and (2) the axial fan in compressor compartment, which produces a sound-power level of 50.2 dBA.

From the sound-power level spectra in Table 1 - d & e, the dominant frequency occurs at 1000 Hz, due to the rotating fan blades, with additional broadband turbulent fan noise observed at 200 Hz to 1600 Hz.

Therefore the increased sound-power level at the rear surface of the IRF unit is related to the aerodynamic noise generation by the centrifugal fan situated at the rear of the unit.

Table 1 *Total sound power level (A-weighted) and frequency spectrum of the IRF unit, operation with different internal noise sources.*

Operation of the appliance	A-weighted total sound power level, L_{WA} (dBA)	Frequency spectrum of sound power
a) Only the propeller fan in the BF-unit	41.1	
d) both compressors (variable speed drive, VSD) in the compressor unit	40.7	
c) the axial fan in the compressor unit	50.2	
d) the centrifugal fan in the FF-unit	56.7	
e) The entire system in operation	57.6	

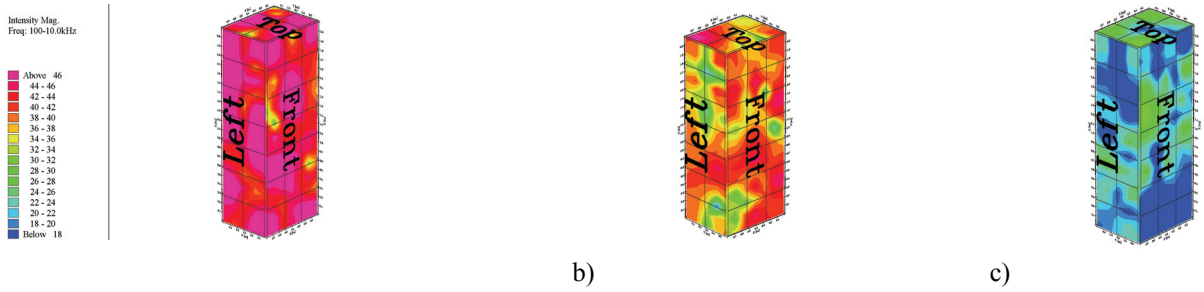
5.2 Replacement of individual active components

The results presented in Section 5.1 reveal the dominant sources of noise in the IRF unit. In the follow-up, we confirmed this by measuring the sound intensity and creating a sound image, which are shown in Figures 6 and 7, respectively. A sound image was recorded in the following three cases:

a) all internal sources of noise are in operation (axial fans in the compressor compartment, centrifugal fan in the FF compartment and both compressors),
b) all elements are in operation, except the centrifugal fan in the FF-compartment,
c) all elements are in operation, except the centrifugal fan in the FF-compartment and the axial fan in the compressor compartment.

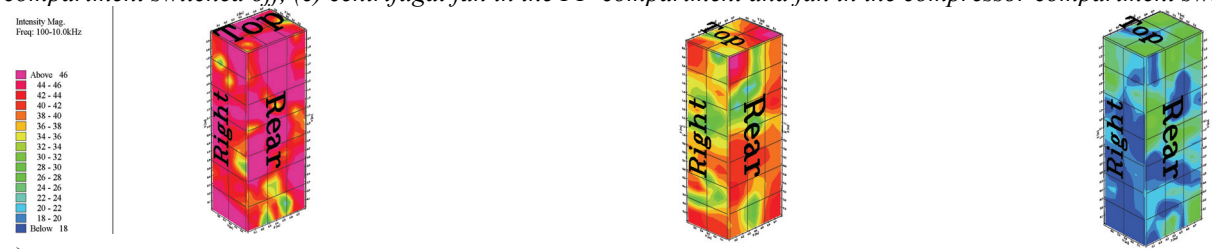
The maximum density of the acoustic energy is in the region of the centrifugal blower, shown on the left side of Figure 6a and 7a. The images show clearly how the noise is generated by the centrifugal fan and at the elements of the connecting flow tracts where local flow velocity is high.

The second important noise source is the axial fan in the compressor unit, which is positioned on an extractable holder (Fig 6 b and Fig 7 b). The same conclusions are obtained when the sound-power level and sound-power level spectra are analyzed (Table 1c).



a) b) c)

Fig 6:*Sound intensity field image of the IFR, left front view: (a) all elements in operation, (b) centrifugal fan in FF-compartment switched off, (c) centrifugal fan in the FF-compartment and fan in the compressor compartment switched off.*



a) b) c)

Fig. 7 *Sound intensity field image of the IFR unit, right rear view: (a) all elements in operation, (b) centrifugal fan in FF-compartment switched off, (c) centrifugal fan in the FF-compartment and axial fan in the compressor compartment switched off.*

The structural noise was assumed to be of minor importance. Since intrinsic noise sources are difficult to identify and the characterization of these sources and the transmission structure is essential, the appliance was designed as much as possible in accordance with the recommended practice for the design of low-noise machinery and equipment, [10].

Our measurements show that to radically reduce the noise level, the centrifugal fan in the FF-unit should be replaced with a more appropriate design, and the axial fan in the compressor compartment should also be replaced with two axial fans to allow a more efficient flow-through of the air-field in the compressor compartment and thus a lower level of sound emission. This was also confirmed by measuring the vector field of sound intensity at the front side of the compressor compartment (Figure 8).

Modifications of the IRF unit were performed in three steps. First, a centrifugal fan in the FF-unit was replaced with a more appropriate model, second, the fan in the compressor compartment was replaced with two fans and third, the rotational speed of these two fans was reduced.

Measurements were repeated. In each step, we determined the total sound-power level and corresponding frequency spectra under the following operating conditions:

1. operation of an unmodified IRF unit,
2. operation of the IRF unit with a new centrifugal fan installed in the FF-unit,
3. operation of the IRF unit with a new centrifugal fan installed in the FF-unit and two axial fans installed in the compressor compartment,
4. operation of the IRF unit with a new centrifugal fan installed in the FF-unit and two axial fans installed in the compressor compartment, operation with reduced rotational speed.

Table 2 shows the results obtained. Reduction of rotational speed was justified with adequate cooling power and distribution of temperature. Rotational speed was reduced from 2150 to 1800 rpm.

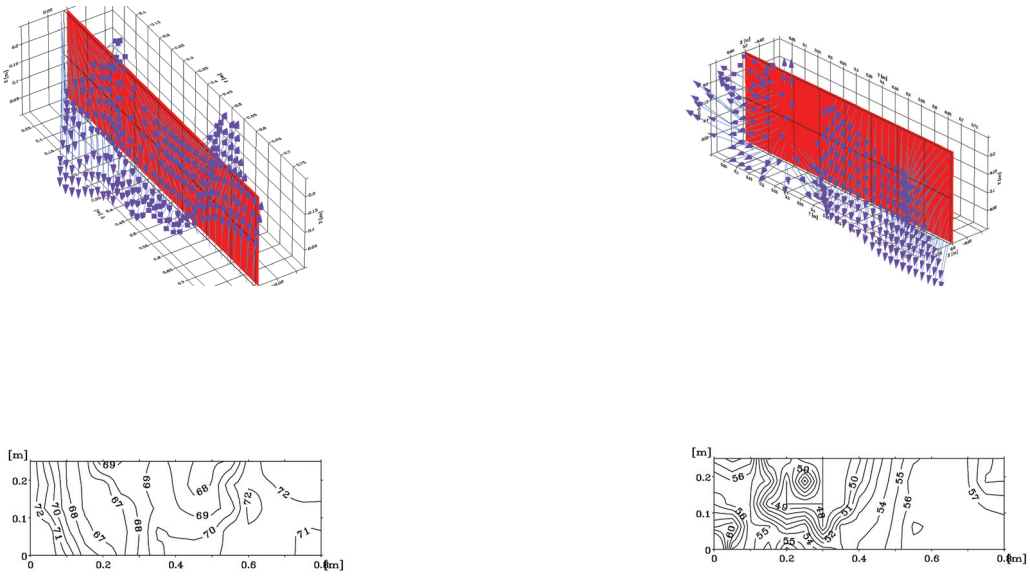


Fig. 8 *Vector and surface representation of sound intensity at the front side of the compressor compartment: the left side indicating the initial situation, the right side showing the situation after modification (installation of two axial fans), represented are frequencies from 200 Hz to 10 kHz.*

Acoustic measurements of individual elements (as described in Section 5.1) have shown that some internal noise sources require either modification or replacement. In addition the total sound-power level significantly exceeded the expected and desired values and measurements of sound intensity and sound imaging during the three operating regimes show how partial noise source dominants.

The original centrifugal fan required replacing with a more appropriate one. As seen from Table 2 (case 1), the old centrifugal fan features both narrow band and broad band noise sources. The noise is generated at the installed fans and at the elements of the connecting flow tracts where the local flow velocity is the highest. The aerodynamic noise generated by the fans comes from a combination of the discrete noise frequencies relating to the number of blades and their rotational speed, i.e., the blade-passing frequency and its harmonics, and the broadband noise or turbulence caused by the aerodynamic fluctuations of the forces applied by the fluid on the rotor blades of the fan. This unsteady loading forms a source system resulting in acoustic propagation in the surrounding medium up to the listener's ear. The aerodynamic forces brought into play, steady or fluctuating, are represented by a source that is dipolar in nature, [10]. Several mechanisms of noise generation coexist, without it always being possible to provide evidence of a dominant source. Therefore, to better understand broadband-noise generation mechanisms, a precise knowledge of the flow behavior over the impeller is vital.

In replacing the original centrifugal fan with another more appropriate one, forward sweeping blades were selected in place of the original backward swept blades. The resultant reduction in broadband noise is due to the backward sweeping blades that produce less tip vortex interaction with neighboring blades. Reduction of the narrow band noise sources was achieved because of the angled leading end trailing edge of the fan blades. Improved aerodynamics also means the new fan rotates more slowly. The result is a reduction in the sound-power level from 57.6 dB(A) to 51.1 dB(A). Furthermore, the centrifugal fan in the BF-unit no longer contributes significantly to the total sound-power level of the IRF unit. The same applies for the refrigerator compressors. In our further noise reduction process, the total appliance noise was mainly dependent on the noise generated by the fan in the compressor compartment. However, reduce the noise emitted from the compressor unit required additional research work, which is described in the work of Holeček et al. [13].

After the appropriate modification/replacement and installation of the two axial fans, we achieved a sound-power level of 46.1 dB(A), (Fig. 10).

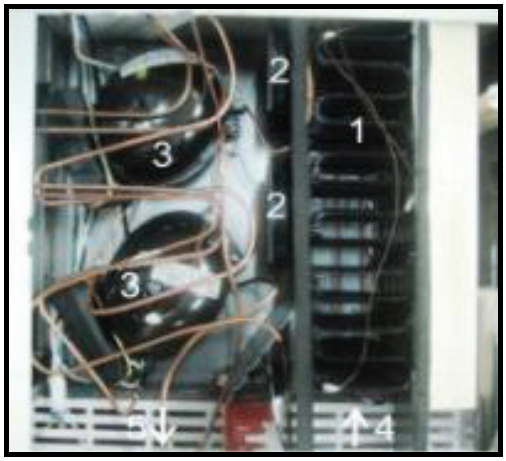
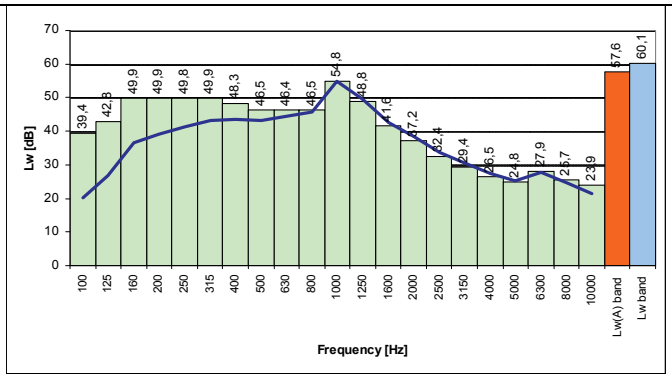
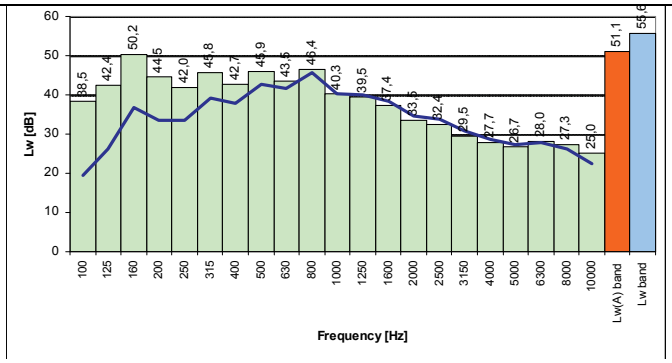
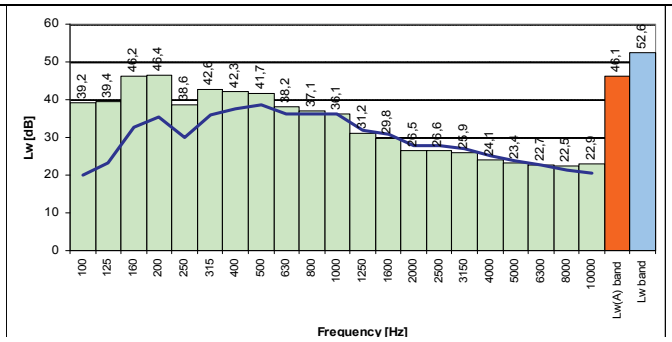
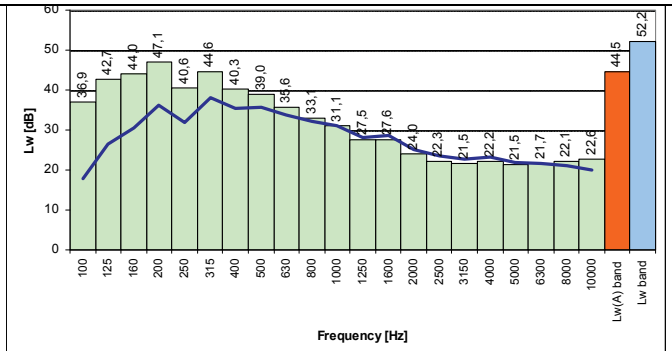


Fig. 10 *Elements of the compressor unit (optimized design): (1) condenser, (2) two axial fans, (3) two variable speed drive (VSD) compressors, (4) inlet of air flow, (5) outlet of air flow.*

Table 2 *Total sound power-level (A-weighted) and frequency spectrum of the modified IRF unit, operation with different noise sources.*

Operation of the appliance	A-weighted total sound power level L_{WA} (dBA)	Frequency spectrum of sound power
1. Operation of an unmodified IRF unit	57.6	
2. Replacement of the existing centrifugal fan in the FF-unit with a new centrifugal fan	51.1	
3. The axial fan in the compressor chamber replaced with two axial fans	46.1	
4. Reduction of the rotational speed of both axial fans in the compressor compartment	44.5	

The frequency spectrum of the sound pressure at the front side of the compressor unit of the modified (optimized) design shows an improvement in 1/3 of the octave for about 5 dB of the sound pressure level (Fig. 11).

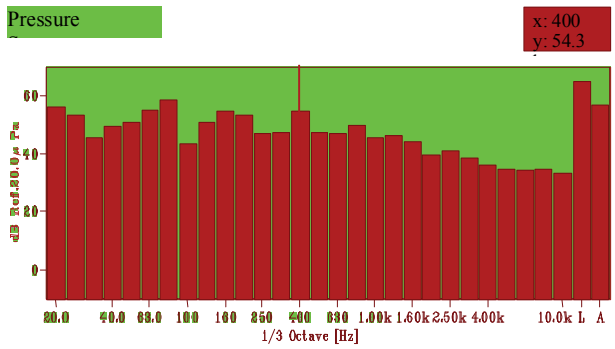


Fig. 11 *Sound pressure level spectra of the compressor unit modified design.*

This last measurement shows that we can achieve a sound-power level of 44.5 dB(A) if we reduce the rotational speed of the compressor compartment fans from 2150 rpm to 1800 rpm. We verified whether such a modification would still acceptable according to the required cooling parameters, and we received a positive response. Thus we had finally achieved a significant lowering of the sound-power level by 13.1 dB(A), from the initial an 57.6 dB(A) to 44.5 dB(A).

6. CONCLUSION

Development trends of large home appliances continue to emphasize the need for quieter operation. We conducted acoustic measurements on an IRF unit, with the aim of reducing its sound emissions. Under free-sound-field conditions, we determined the total and third-octave level of sound power, and by measuring sound intensity, we were able to perform sound imaging. By measuring the sound intensity on all five of the emission surfaces of the IRF unit, we located the main sources of noise emissions. From this, we were able to conclude that the increased sound intensity at all five sides of the IRF unit is related to the aerodynamic noise generated by the rotor of the centrifugal fan in the FF-compartment and to the noise generated by turbulence in the airflow distribution channel. The reason for this was the installation of an inappropriate type of centrifugal fan in the FF-compartment. By replacing this with a more appropriate design, we managed to lower the sound-power level from 57.6 dB(A) to 51.1 dB(A).

Target noise values for the IRF unit were still lower than the achieved values. Therefore, we took the extra step of replacing the fan in the compressor compartment. Optimal flow of the air was obtained by replacing the original fan with two axial fans. This resulted in a further lowering of the noise level from 51.1 dB(A) to 46.1 dB(A). As the target value was below 45 dBA, we took an additional measure of reducing their rotational speed from 2150 to 1800 rpm. We checked the impact of this action on the functional and energy properties of the appliance. After obtaining a positive response, we decided to implement this change and thus achieved the target value of 44.5 dB(A).

REFERENCES

[1] ISO 11688–2 Acoustics, “Recommended practice for the design of low-noise machinery and equipment, Part 2: Introduction to the physics of low-noise design.”

[2] Beranek, L. (1988): Noise and Vibration Control. Cambridge: Institute of noise control engineering.

[3] Crocker, M. J. (1997): Noise and vibration control. John Wiley &Sons, Inc.

[4] Doebelin, E. (1990): Measurement system. New York: McGraw-Hill Book Company.

[5] Fahy, Frank J. (1989): Sound Intensity. London: Elsevier Science Publisher Ltd.

[6] Holeček, N. “Acoustical laboratory in Gorenje,” Invited Papers, Proc. First Congress of Slovenian Acoustical Society, Portorož, Slovenia (1998), pp. 369-374,

[7] ISO 3745 2003 Acoustics - Determination of sound power levels of noise sources - Precision methods for anechoic and semi-anechoic rooms, International standard (International organization for standardization, Geneva, Switzerland, 2003).

[8] IEC 61672-1:2002 Electroacoustics – Sound level meters –International Electrotechnical Commission,

[9] IEC 61260:1995 Electroacoustics - Octave-band and fractional-octave-band filters International Electrotechnical Commission, CENELEC, Brusselas 1995

[10] S.J Yang and A.J. Ellison, Machinery noise measurement (Clarendon press, Oxford, 1985)

[11] Bruel&Kjaer, Technical Documentation Noise Source Location Software Type 7681 (Bruel&Kjaer ,1994)

[12] Nikola Holeček, Brane Širok, Marko Hočevar, Rudolf Podgornik and Rok Grudnik, “Reducing the noise emitted froma domestic clothes-drying machine”, Noise Control Eng. J.,54(3), 137–145, (2006).

[13] Holeček, N., Eberlinc, M., Hočevar, M., Širok, B. (2009): Experimental investigation of noise generated by multifunctional refrigerating units. V: The 38th International Congress and Exposition on Noise Control Engineering, Ottawa, Kanada, 23–26 august. *Proceedings of inter-noise 2009: innovations in practical noise control*. Washington: Institute of Noise Control Engineering.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

INVESTIGATION OF THE ACOUSTIC FIELD ON THE PLATFORM OF A CONCRETE PREPARARTION STATION

Nicolae Herisanu[1], *Vasile Bacria*[2]

[1] "Politehnica" University of Timisoara, Faculty of Mechanical Engineering, Romania, herisanu@mec.upt.ro
[2] "Politehnica" University of Timisoara, Faculty of Mechanical Engineering, Romania, bacria@mec.upt.ro

Abstract - *On the platform of a concrete preparation station one can identify some plants and operations which generate noise. This noise can affect people inside the platform as well as the neighborhood. In this paper we present the results obtained in the investigation of the acoustic field on the platform of a concrete preparation station emphasizing the noise sources, propagation way, frequency spectra, statistic distribution, characteristic parameters, noxious effects and some methods to eliminate undesirable effects.*

1. INTRODUCTION

Within the platform of a concrete preparation station are present various machines, equipments and operations such as the concrete preparation unit, cement bunkers, trucks, tractors, the concrete mixing process and others. The noise generated by these ones originates in the mechanical, electromagnetical, aerodynamical and hydrostatical processes which take place during working regimes. Thus, the causes of noise appearance during the mentioned processes are the shock interaction of two or more bodies, the friction of interacting surfaces, aerodynamical turbulences, forced oscillations of the rigid bodies, the action of variable electromagnetic forces (especially at electrical operated groups), the vibration of road or membrane-shaped parts, pulsating pressure in hydrostatic operated devices, the contact between the wheels and the rolling surface. The noise generated on the platform of a concrete preparation station can be characterized by the equivalent noise level defined by:

$$L_{Aeq,T} = 10\lg\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}\frac{p_A^2(t)}{p_0^2}dt\right] \qquad (1)$$

where $L_{Aeq,T}$ is the continuous equivalent acoustic pressure level A-weighted, measured in dB, determined in an interval which starts at t_1 and ends at t_2, p_0 is the reference acoustic pressure and $p_A(t)$ is the weighted instantaneous pressure of the acoustical signal. Effectively, the equivalent noise level can be obtained through computations using Eq.(1) or it can be directly measured and computed using for example the Bruel&Kjaer 2250 noise analyzer, which allows the measurement and recording of many characteristic parameters of the sound as well as the spectral analysis in frequency bands and statistical distribution of the acoustic level.

In this paper we investigate the acoustic field on the platform of a concrete station.

2. NOXIOUS EFFECTS OF THE NOISE ON THE PLATFORM

The noise generated by machines, equipments, plants and operations within the platform of a concrete preparation station affects human being's nervous system generating psycho-physiological modifications, blood flow modifications, sleeping disturbances and adversely affects the visual and endocrine functions, generating also bio-chemical disturbances. Under the influence of severe acoustic conditions, the blood pressure raises while the pulse accelerates, intracranial vascular pressure could be significantly increased and breathing rhythm is changed as well. Strong noise can produce nervous irritations through the cerebral crust whereas the fatigue process accentuates and physical reactions are weaken. In some cases even asthenia and nervous illness are unfortunately appearing. An intense exposure to noise also produces hearing tiredness and sonorous trauma. The noisy environment favors an increased level of danger of accidents, because the speech intelligibility is lower and acoustical warnings are hard to be perceived. Last, but not least, even the employer is affected, because the noise exposure reduces the working productivity.

The noise that propagates outside of the platform of a concrete preparation station is detrimental for persons leaving in the neighborhood.

In order to avoid noxious effects of the noise upon the workers, the maximum admissible limit of daily exposure at working places is established at 87 dB(A) [10]. In those places where the daily noise exposure exceeds 80 dB(A), the employer must provide employees with individual protection equipment against noise and in those places where the personal daily exposure exceeds 85 dB(A), the employees are obliged to bear individual protection equipment against noise [10].

In the same time, in order to protect persons outside the platform of a concrete preparation station, the maximum admissible limit of the equivalent noise level at the border of the functional zone of the platform of a concrete preparation station is established by the Romanian standard STAS 10009-88 "Urban acoustics" at 65 dB(A).

The acoustic field generated by sources within a platform of a concrete preparation can produce unpleasant effects upon

inhabitants from the neighborhood. In this respect, the above mentioned standard establishes that the location of residential buildings on streets which belong of different technical categories or at the limit of some functional areas, as well as the organization of the road traffic must be arranged so that the limit for the exterior noise level do not exceed 50 dB(A) or the C_z45 curve near the protected zone. The noise level is measured in a point located at 2 meters distance from the building's wall, according to SR 6161-1:2008. By investigating the acoustic field generated by sources within a platform of a concrete preparation station one can establish if this one generates a comfortable or uncomfortable environment for people. In the case when the noise level exceeds the admissible values it can be established some methods aimed at decreasing the noise.

3. INVESTIGATION OF THE ACOUSTIC FIELD

Taking into account the shape and size of perturbation sources on the platform of a concrete preparation station, it forms a very complex acoustical field by overlapping the waves generated by these sources. These ones could be spherical, cylindrical or even plane waves at long distance from the source. Sometimes it forms a very complex acoustical field by overlapping reflected waves by the neighborhood houses and direct waves. The acoustic pressure in a point of the field is obtained by adding the acoustic pressures corresponding to each type of waves.

In the case of vibration propagating as spherical waves in an elastic, homogeneous and isotropic environment, the acoustical pressure in a point of the acoustic field is determined by the expression [1]:

$$p = \rho_0 \omega \frac{A}{r} \mathbf{sin}(\omega t - kr + \alpha) \tag{2}$$

where r is the radial coordinate, A is the amplitude of spherical wave having the frequency $f = \omega / 2\pi$ which propagates from the source with a speed c and $k = \omega / c$ is the wave number.

In the case when the sound propagates by cylindrical waves traveling uniformly, the acoustical pressure can be written [1]:

$$p = A\left[J_0(kr) + iY_0(kr)\right]e^{i\omega t} \tag{3}$$

where r is the cylindrical coordinate, A is a constant, J_0 is the Bessel function of the first degree and zero-th order and Y_0 is the Bessel-Neumann function of the second degree and zero-th order.

In the same way, taking into account that the propagation of the perturbation can happen under the form of plane waves and considering only the case of divergent wave, the acoustic pressure in a point of the acoustical field is given by [1]:

$$p = \rho_0 \omega A \mathbf{sin}(\omega t - kr + \varphi) \tag{4}$$

Propagation of spherical, cylindrical and plane waves is characterized by the variation of the acoustic pressure in a specific point of the acoustic field.

Using the instantaneous acoustic pressure one can compute the instantaneous sound pressure level defined by the equation:

$$L = 20 \mathbf{lg} \frac{p}{p_0} \tag{5}$$

where p is the acoustical pressure in a point of the acoustic field, p_0 is the reference pressure $p_0 = 2 \cdot 10^{-5}$ [N/m^2].

The same instantaneous pressure can be used also for computing the equivalent acoustic level defined by Eq.(1). Using the instantaneous sound pressure level one can compute the equivalent noise level corresponding to a working day within the platform of a concrete preparation station $L_{Aeq,Te}$ [dB] and using the values of this one can determine the daily personal exposure of workers and moreover, one can compute the weakly exposure [10].

Effectively, the equivalent acoustic level can be determined through computations using Eq.(1) or it can be obtained directly by measurements using specific equipments.

Taking into account the large number and the variety of sources which participate in generating the noise as well as the nature of generated acoustic waves, the acoustic field which forms inside and outside the platform of a concrete preparation station is extremely complex and its investigation is indicated to be performs experimentally.

Measurements were performed using the Bruel & Kjaer Analyzer type 2250, which allowed the recording of sound characteristics. In the same time, an anemometer, which is also a thermohygrometer has been employed for the assessment of environmental conditions (air speed, humidity and temperature).

The measurements were performed during the day time using simultaneously two identical analyzers: one of them was intended to record the noise on the platform of the concrete preparation station while the other one was intended to assess simultaneously the corresponding noise at 2 meters distance from the residential area. Such measurements were performed in four measurement points for different noise sources on the platform of the concrete preparation station, for different working regimes. For determining the characteristic parameters of the acoustic field, a method established in [8-11] was resorted to. We have investigated 8 working conditions, as follows: 1 – functioning of station's compressors; 2 – functioning of station alone; 3 – discharge of cement in bunkers; 4 – normal functioning of the station (including mixers); 5 – functioning of the station overlapping cement discharge; 6 – functioning of the station overlapping cement discharge as well as frontal loader displacements; 7 – displacements of concrete transporters and concrete pumps; 8 – displacements of supply machines. The values recorded for the equivalent noise level for these samples of measurements taken simultaneously on the platform and near the residential area are presented in table 1.

Table 1 *Values of the equivalent noise level*

Sample		1	2	3	4
L_{Aeq} [dB]	on site	54.5	56.5	57.8	69.5
	building	55.4	55.9	55.6	58.8

Sample		5	6	7	8
L_{Aeq} [dB]	on site	73.7	70.5	83.9	73.2
	building	59.5	65.5	61.3	72.5

In the same time, the diagrams emphasizing the time-history of L_{eq} and spectral and statistical distributions recorder during measurements are presented in figs.1-6.

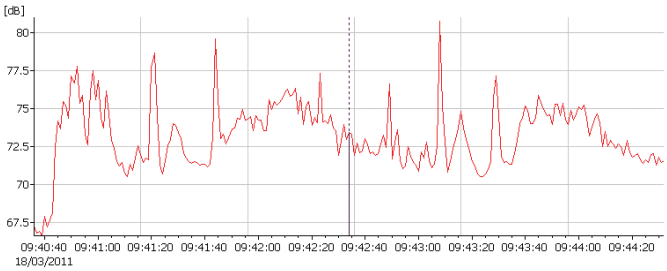


Fig. 1 *Time-history of L_{Aeq} for sample no.5, near the source*

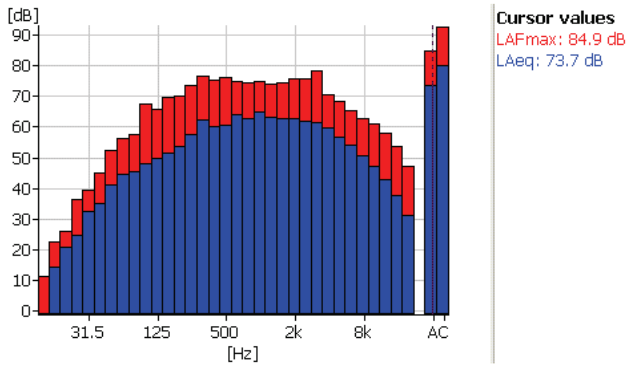


Fig. 2 *Spectral distribution of the noise A-weighted in 1/3 octave bands for sample no.5, near the source*

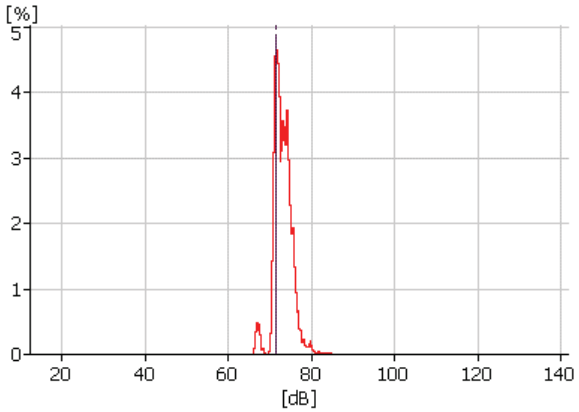


Fig. 3 *Statistical distribution of the noise for sample no.5 near the source*

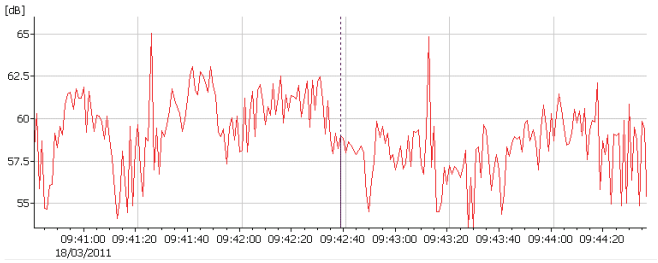


Fig. 4 *Time-history of L_{Aeq} for sample no.5, near the residential area*

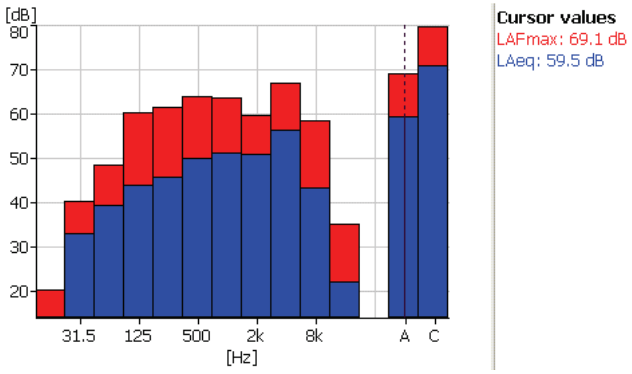


Fig. 5 *Spectral distribution of the noise A-weighted in 1/1 octave bands for sample no.5, near the residential area*

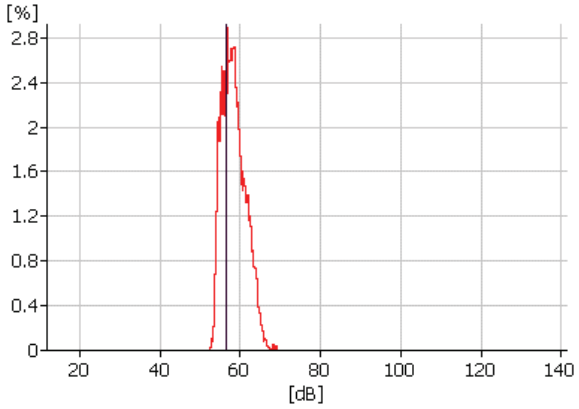


Fig. 6 *Statistical distribution of the noise for sample no.5 near the residential area*

The results of measurements were stored in a data base designed for the investigation of noise climate within a platform of a concrete preparation station in the frame of the Acoustics and Vibration Laboratory from Politehnica University of Timişoara, which is accredited by RENAR (the national accreditation body) according to ISO-17025 for noise and vibration measurements.

4. DECREASING THE NOISE LEVEL

Using the results of the measurements, the acoustic climate within the platform of a concrete preparation station can be characterized. In this way, during the functioning of the machines, equipments and plants on the platform of the concrete preparation station, an exceeding of the admissible noise level were identified for each of the investigated sample. More precisely, the equivalent noise level measured at 2 meters distance from the building's wall exceeded the admissible limits as follows: 5.4 dB(A) for the first working

regime defined above, 5.9 dB(A), 5.6 dB(A), 8.8 dB(A), 9.5 dB(A), 15.5 dB(A), 11.3 dB(A) and 22.5 dB(A) respectively for the next working regimes.

One can conclude therefore that the acoustic sources from the platform of the concrete preparation station generate noise which produces some unpleasant effects upon inhabitants from neighborhood. Taking into account the noise level and spectral distribution measured at 2 meters distance from the building's wall, it is necessary to perform some acoustical arrangements on the platform. This acoustical arrangement consists in building of a phonic barrier between the platform of the concrete preparation station and buildings, acoustical insulation of the concrete preparation unit, re-arrangement of the interior yard of the platform, which will be covered by asphalt in order to ensure a more silent functioning of the machines inside the platform.

5. CONCLUSIONS

In order to establish the way in which the platform of a concrete preparation station generates noise which affects the environment, it is necessary to experimentally investigate the noise from the platform.

The values obtained for the characteristic parameters of the noise are compared with admissible limits. From this comparison, one can conclude that the environment is affected or not by noise and noise mitigation measures can be taken if needed.

The presented method of investigation and mitigation proves to be very efficient and can be applied in similar practical situations.

REFERENCES

[1] N. Enescu, I. Magheţi and M.A.Sârbu, *Acustică tehnică*, Bucureşti:Ed. ICPE, 1998

[2] P. Bratu, *Acustica interioară pentru construcţii şi maşini*, Bucureşti:Ed. Impuls, 2002

[3] M. Grumăzescu, A. Stan, N. Wegener, V. Marinescu, *Combaterea zgomotului şi vibraţiilor în tehnică*, Bucureşti: Ed. Tehnică, 1964

[4] E.Ia. Iudin, *Izolarea împortriva zgomotelor*, Bucureşti: Ed. Tehnică, 1968

[5] M. Gafiţanu, V. Merticaru, V. Focşa, L. Bilborosch, *Vibraţii şi zgomote*, Iasi: Ed. Junimea, 1980

[6] V. Bacria, N. Herişanu, "Decreasing the noise level on a construction site", *Ses. Com. St. SIMEC 2011, Ed. Matrix Rom, Bucureşti*, 2011, pp.15-22

[7] N. Herişanu, V. Bacria, "Consideration upon the acoustic field generated by sources within a disco-club", *XXII Conf. Noise and Vibration,* 20-22 Oct. 2010, Niş, Serbia, 2010, pp.25-28

[8] *** STAS 10009-88. *Acustica în construcţii. Acustica Urbană. Limite admisibile ale nivelului de zgomot*

[9] *** STAS 6161/3-82. *Acustica în construcţii. Determinarea nivelului de zgomot în localităţile urbane. Metodă de determinare*

[10] *** *Norme generale de protecţia muncii 2002, INCD pentru Protecţia Muncii, Bucureşti*

[11] *** STAS 7150-77 *Acustica în industrie. Metode de măsurare a nivelului de zgomot în industrie*

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

DESIGN AND IMPLEMENTATION OF ON−LINE DATABASE OF NOISE SOURCES

Jelena Tomić, Nebojša Bogojević, Bojan Tatić, Zlatan Šoškić

Faculty of Mechanical and Civil Engineering, University of Kragujevac, tomic.j@mfkv.rs

Abstract - *The paper presents the concept, structure and implementation of relational database for description of noise sources, which is developed within the framework of the project "Development of methodologies and means for noise protection of urban areas". Database is founded on results of research activities connected to description of noise sources, performed in European Union during the previous decade. The research activities are the basis for contemporary noise protection standards and methods, and they showed that development of a public national database of noise sources contributes significantly to noise mapping and noise protection planning. The database presented in the paper enables detailed description of point sources and line sources by storing data about sound power, spectra and spatial distribution, and for complex noise sources provides possibility for storing mathematical relationships which describe noise emitted by the sources. The access to the database data is possible through standard SQL queries, which is suitable for development of software tools and components for noise mapping. The database is accessible on−line over the Internet, with read rights granted without limitation, whereas rights for writing the data are granted only to developers.*

1. INTRODUCTION

During the last decade European Union has been implementing the strategy for combating noise according to the Environmental Noise Directive (2002/49/EC) [1], which was passed by the European Parliament in June of 2002. Under this directive, Member States were obliged to make strategic noise maps no later than 30th June 2007. Furthermore, the competent authorities, based on results of noise mapping, had to draw up action plans designed to manage noise issues and effects, including noise reduction if necessary, no later than 18th July 2008. In accordance to strategy, FP5 project "Harmonoise" [2], FP6 project "Imagine" [3], and FP7 project "Silence" [4] were established. "Harmonoise" project developed common European noise prediction models for road and railway traffic. Project "Imagine" improved the existing models and developed common European noise prediction models for aircraft and industrial noise. Project "Silence" has been developing methodologies for drawing of Noise Action Plans. Also various non-European projects [5][6][7][8] were established to support combating noise.

As Serbia is in accession process to the European Union, Serbian legislation related to noise protection is in accordance to Environmental Noise Directive. Law on environment noise protection [9], which was passed by Serbian parliament in 2009, and following by-laws [10][11][12] determinate principles of assessment of noise impact, noise mapping and drawing of Noise Action Plans. Serbian Ministry of Education and Science funded project "Development of methodologies and means for noise protection of urban environment" (acronym "urbaNoise") [13], which should support providing measures prescribed by legislation, that are still not provided. The project is realized by three major Serbian state universities, University of Kragujevac, represented by Faculty of Mechanical Engineering Kraljevo, University of Niš, represented by Faculty of Occupational Safety and University of Belgrade, represented by the Faculty of Traffic Engineering. The project goals are:

- development of national noise assessment methodologies harmonized with EU;
- development of national database of noise sources;
- development of software tools for local noise mappings;
- construction of laboratory facilities for testing of acoustic materials;
- design of modular noise barriers from waste materials.

Databases represent significant tool for data collection, classification and analyses, what is important for development of models for noise prediction and its further improvement. While the "Harmonoise" and "Imagine" projects provided databases for prediction models of railway noise, aircraft noise and industrial noise, database developed within "urbaNoise" project is intended to describe industrial and communal noise sources. Communal sources, like noise of public service facilities, schools and nurseries, recreational objects, sport facilities, workshops, shopping malls and other noise sources typical for urban life, are not included in EU projects.

This paper presents Serbian national database for urban noise sources developed within "urbaNoise" project. The second section of the paper defines requests for creating database of noise sources, which structure is described in the third section. In the end of the work, after describing database implementation, conclusions are given with ideas for further usage and improvement of the database.

2. REQUESTS

Databases of noise sources represent significant tool for noise mapping purposes as well as for statistical analyses. As concluded in project "Imagine", creation of national databases is necessary due to differences between vehicles, road and rail structures, industrial sources in various countries, and also from cultural differences that affect noise sources.

The Serbian national database of noise sources is intended to describe industrial and communal noise sources. Noise emitted by communal or industrial sources may depend on many parameters, but database should be simple and practical to use, so it should contain minimal number of data that describe noise source. Also, measurements and collection of such data often require extensive time and expertise, so the proper data selection represents important goal in the database design. However, all data important for prediction of noise levels according to the relevant models must be included. The data which are needed for the models used in the project "urbaNoise" for noise mapping are:

- Type of noise source (point source or linear source)
- Noise type (continuous, variable, intermittent, impulse)
- Emitted sound power level
- Emitted sound power level spectrum
- Directivity
- Name of the source

The information about sound power can be submitted in two ways: by numeric values of emitted sound power and octave/third octave power spectrum or by mathematical formula that enables calculation of emitted sound power.

In purpose of data visibility and easier and efficient statistical analysis, noise sources in database are organized in the following way:

- The first level, category of the source, enables grouping of noise sources according its function;
- The second level, subcategory of the source, enables classification within a certain category according to performance or construction characteristics of the noise source.

The database is not intended to be used only by participants of project "urbaNoise", but also to permit public access to reading collected data, so the third parties could use data as input in software tools for noise mapping. It should be accessible over internet and should respond to standard SQL queries. Taking into consideration that credibility and integrity of the data in database must not be threatened, data submitting should be restricted only to participants of "urbaNoise" project. For security reasons, input access should be organized in two levels, operator level and administrator level. Operator level is lower, and allows operator to input data which describe noise sources. Administrator level, as higher, enables administrator to input categories and subcategories as well as access rights management.

3. DATABASE STRUCTURE

Figure 1 presents the Enhanced Entity−Relationship (EER) diagram of the database structure. EER diagrams illustrate the logical structure of databases, e.g., the relationships between entities (tables) in a database. Each entity (for example a person) is described by its attributes (name, gender, age might be attributes of the person entity). An attribute or set of attributes that uniquely identifies a particular entity is primary key (for example, social security number might be the primary key for the person entity). Foreign keys are attributes that define relationships between entities (for example, between persons, their documents or possessions). The attributes of a foreign key in one entity are the attributes of a primary key in another entity (for example, license number may be a foreign key for the person entity). "1-to-1" relationship between two tables indicates that each record in the first table corresponds to one, and only one, record in the second table (one person has one driving license). "1-to-many" relationship indicates that each record in the first table corresponds to one or more records in the second table, but each record in the second table corresponds to only one record in the first table (one person may have several cars).

Noise source is represented by the table *Source*, which contains the following attributes (columns):

- *SourceID*, the primary key of the table
- *source_name*, the name of the source
- *source_description*, the textual description of the source
- *Subcategory_SubcategoryTypeID*, key to the subcategory of the source
- *SourceType_SourceTypeID*, key to the type of the source
- *NoiseType_NoiseTypeID*, key to the type of the emitted noise
- *PowerDesciption_PowerDescriptionID*, key to the method of description of the emitted power

Administrator sets the data on source types, noise types, categories and subcategories into the corresponding tables: *SourceType*, *NoiseType*, *Category* and *Subcategory*, respectively. When entering data about noise source, operator selects one of the values contained in those tables. Tables *NoisaType*, *SourceType* and *Subcategory* are linked by "1−to−many" relationships to the table Source, so foreign keys *SourceType_SourceTypeID*, *NoiseType_NoiseTypeID* and *Subcategory_SubcategoryID* determine to which source type, noise type and subcategory noise source belongs. Table Subcategory contains foreign key *Category_CategoryID*, that keeps information about category to which subcategory belongs.

Noise source may be described by emitted power and spectral components of power or by mathematical equation. The key *PowerDesciption_PowerDescriptionID* in the table *Source* determines which description method for noise source is used, i.e., which of the tables *PowerSpectrum* or *NoiseEquation* contains the corresponding data.

The table *PowerSpectrum* is linked by "1−to−1" relationship to the table *Source* by the key *Source_SourceID*. This table contains information about emitted sound power level and emitted sound power spectrum. Operator may enter octave or

third octave power spectrum. Emitted sound power by the noise source is the only mandatory attribute.

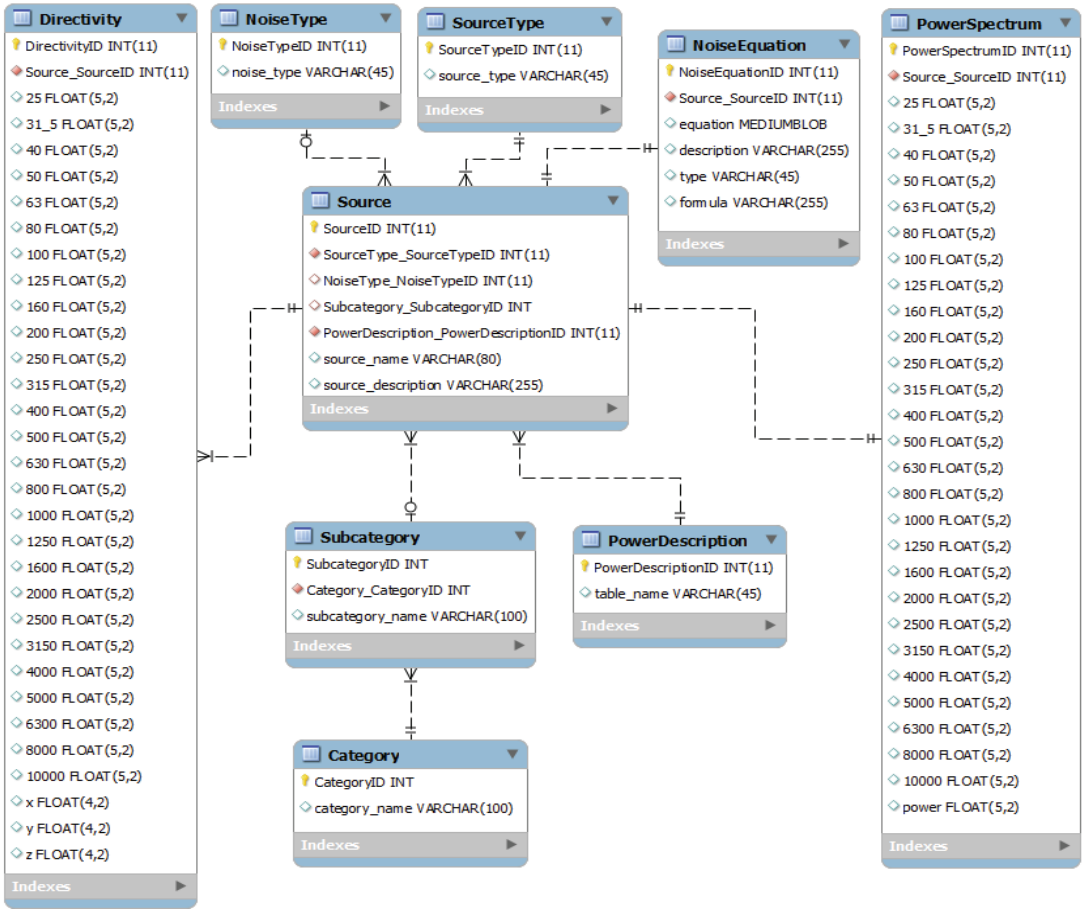


Figure 1: *EER diagram of the database of noise sources used in "urbaNoise" project*

The table *NoiseEquation* is linked by "1−to−1" relationship to the table Source by the key *Source_SourceID*. This table contains information about mathematical formula that enables calculation of the emitted sound power. Mathematical formula is stored in form of picture with .png or .jpg extension in the column *equation*. Column *type* keeps information about type of uploaded picture file (.png or .jpg). Textual explanation and content of the formula are stored in the column *description*. Optional, operator may enter textual expression of the formula in some programming language, which is stored in the column *formula*.

The information about directivity of the source emission is entered to the table *Directivity*. The table *Directivity* is linked by "1−to−many" relationship to the table Source by the key *Source_SourceID*. For every noise source, sound power and octave/third octave power spectrum can be submitted for several directions. Each direction is determined by attributes x, y and z, which represent point in the coordinate systems with noise source as origin.

4. IMPLEMENTATION

The database was created using MySQL database engine and it is running under Linux operating system on the web server of Faculty of Mechanical Engineering Kraljevo. The main reasons to design SQL database were high speed data handling, scalability, security and ability to support significantly more database users than Microsoft Access, which was used in the projects “Harmonoise” and “Imagine”. The database is developed by Group for Software and Hardware support and applied and administered by Group for Methodologies for Noise Impact Assessment.

The user interface to the database is developed using PHP programming language which enables generation of active HTML pages. The interactive user interface combined with presented database gives possibility to less experienced users to manipulate with new and collected data. The designed user interface enables complete database manipulation which means entering new data, editing and deleting existing data, preview collected data in HTML as well as generating reports in PDF format.

The access to the database is possible over the internet address www.mfkv.kg.ac.rs/urbanoise/dbnoise. Due to safety and security reasons, the access to the database is planned to be realized in two levels. The collected data will be publicly available on the given internet address, but the data manipulation will be granted only to the developer team and project participants.

The data which are stored in the database may be interactively filtered by categories and subcategories of the urban noise sources. The general criteria when forming categories and subcategories of noise sources are:

- Categories and subcategories should logically organize noise sources according to their main

functions and construction characteristics (for example motors, pumps, fans, etc.).

- Categories and subcategories should be selected to include statistically relevant number of representatives.
- Quality of the source in terms of noise emissions and extent of applied noise control will be categorized into "poor", "average" and "good" only.
- Parameter variations will be made in steps that lead to differences in the overall noise level of about at least 2 dB.

Data exchange between the database and the third party software tools for noise mapping may be realized through SQL query or XML. SQL (Structured Query Language) is a programming language designed for accessing, making and managing databases. SQL queries perform data retrieval, inserting/updating of data, and creation of data objects such as SQL databases and SQL tables. As database should be publicly accessible, SQL query will be the basic tool for data reading. XML (Extensible Markup Language) is a markup language designed to transport and storing of data. It is the most common tool for data transmissions between all sorts of applications.

5. CONCLUSIONS

The database presented in this paper was developed for collecting and storing data that describe industrial and communal noise sources. Also, it may be used for other point or line noise sources with known emitted sound power and/or directivity.

The main purpose of database is its usage by software tools for production of noise maps. Using SQL query or XML the third party software tools for noise mapping may read the data from the database. Data collecting is also significant for statistical analyses that may reveal relations between sources' parameters and emitted sound power.

Experiences gained in "Harmonoise" and "Imagine" projects were used during development of presented database, but the main improvement is reduction of database structure in comparison to the databases developed in mentioned projects, what simplified using of database without losing of accuracy.

Future work on database improvement should be headed in two directions:

- increasing of number of collected noise sources and defined categories in the database;
- description of noise emission by mathematical formulae in order to improve the process of noise mapping, if it is possible.

6. ACKNOWLEDGEMENT

The authors wish to express their gratitude to Serbian Ministry of Education and Science for support through project TR37020.

REFERENCES

[1] "Directive 2002/49/EC of the European Parliament and the Council of June 2002", Official Journal of the European Communities, 2002.

[2] http://cordis.europa.eu/fetch?ACTION=D&CALLER=PROJ_IST&QM_EP_RCN_A=57829

[3] http://www.imagine-project.org

[4] http://www.silence-ip.org

[5] Shi-Won Lee, Seo Il Chang, Young-Min Park, "Utilizing noise mapping for environmental impact assessment in a downtown redevelopment area of Seoul, Korea", Applied Acoustics, Volume 69, Issue 8, pp. 704−714 (2008)

[6] Kang-Ting Tsai, Min-Der Lin, Yen-Hua Chen, "Noise mapping in urban environments: A Taiwan study", Applied Acoustics, Volume 70, Issue 7, pp. 964-972 (2009)

[7] Bo Wang, Jian Kang , "Effects of urban morphology on the traffic noise distribution through noise mapping: A comparative study between UK and China", Applied Acoustics, Volume 72, Issue 8, pp. 556-568 (2011)

[8] Paulo Henrique Trombetta Zannin, David Queiroz de Sant'Ana, "Noise mapping at different stages of a freeway redevelopment project – A case study in Brazil", Applied Acoustics, Volume 72, Issue 8, pp. 479-486 (2011)

[9] "Law on environmental noise protection of Republic of Serbia", Official Gazette of Republic of Serbia, No. 36/2009

[10] "Regulation on noise indicators, limiting values and methods for estimation of noise indicators, annoyance and detrimental effects of noise", Official Gazette of Republic of Serbia, No. 75/2010

[11] "Guidelines on contents and methods of strategic noise mapping and their public presentation", Official Gazette of Republic of Serbia, No. 80/2010

[12] "Guidelines on methodology for design of action plans", Official Gazette of Republic of Serbia, No. 72/2010

[13] http://www.mfkv.rs/urbaNoise

University of Nis
Faculty of Occupational Safety

„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

DECREASING THE NOISE GENERATED BY THE ROAD TRANSPORTATION MEANS

Vasile Bacria[1], *Nicolae Herisanu*[2]

[1] "Politehnica" University of Timisoara, Faculty of Mechanical Engineering, Romania, bacria@mec.upt.ro
[2] "Politehnica" University of Timisoara, Faculty of Mechanical Engineering, Romania, herisanu@mec.upt.ro

Abstract - *In the context of sustainable development and environmental protection, a special issue is represented by noise generation and propagation in the environment. The road transportation means generate noise and vibrations which are highly detrimental for human being's life and activity. The noise generated by road transportation means can be reduced by active and/or passive protection measures. In this paper we present an investigation of the noise generated by the road transportation means in the urban environment. We identify decisive factors which influence the noise level generated by the road transportation means, propagation ways and noxious effects. Results of measurements and an analysis of these results are presented.*

1. INTRODUCTION

Permanently, on the road thoroughfares of the towns it is developed an intense traffic. The road transportation means generate phonic pollution which is highly detrimental for human being's life and activity. Because of its detrimental character and because of its presence in all sectors of life, the phonic pollution represents a major problem occurring in all developed countries. This problem occurs even in Romania and received an increased importance taking into account the restrictions imposed to EU countries.

It is known that Timişoara is the second town in the country, after Bucharest, in terms of rolling stock. The noise generated by the road transportation means depends on the traffic intensity and composition, as well as on the speed of vehicles and it is mainly generated by three sources: the engine, the transmission system and the contact between the wheels and the rolling surface. This noise can be reduced by active and passive protection measures. In this paper we present an investigation of the noise generated by the road transportation means in the urban environment. In this way, we identify the decisive factors influencing the noise level generated by the road transportation means, propagation ways and noxious effects. Results of measurements and an analysis of these results are presented. In order to reduce the noise generated by the road transportation means in Timişoara City, we established and implemented some measures intended to noise decreasing. The effect of the implementation of these measures on noise decreasing is evaluated through new measurements.

2. DECISIVE FACTORS WHICH INFLUENCE THE NOISE LEVEL

The noise generated by the road transportation means is characterized by frequency spectra, acoustic pressure levels and their variation in time. Generally, we can say that the noise sources from the road transportation means have a low frequency and partially a middle frequency character. The noise generated by transportation means taking part in the road traffic arises from the engine, transmission system, braking system, air resistance and contact between the wheels and rolling surface. The noise sources depend on the type of transportation means.

Therefore, in the case of buses, the most important sources are: the engine, the drive links, the gases exhaust, or the chatter between passengers. In case of cars, the noise is generated mainly by the engine, gases exhaust, rolling and brakes. The most important sources of noise in case of trucks are the engine, the drive links, gases exhaust, striking back of the flame and rolling. In case of motorcycles, the noise generated by gases exhaust predominates.

Improper maintenance of transportation means having deficiencies with gases exhaust and braking system generate an increased noise in the road traffic.

The noise generated by the road transportation means depends on the traffic intensity (vehicle/hour) and composition, on the vehicle speed and also on the distance from the street. The level of noise changes once with changing the distance from the source. Knowing the variation in terms of the distance from the source is useful in order to emphasize the effect of the noise generated by the road traffic near to habitation buildings. The traffic composition can change in time producing modifications of the noise level. The traffic noise on streets depends on the vehicle type and speed and also on the nature of the runway's material [7].

3. PROPAGATION WAYS AND NOXIOUS EFFECTS

The noise generated by road transportation means propagates in the environment by spherical or cylindrical waves and at long distance from the source, even by plane waves. In the case of vibrations propagating as spherical waves in an elastic, homogeneous and isotropic environment, the acoustic pressure in a point of the acoustic field is determined by the expression [3]:

$$p = \rho_0 \omega \frac{A}{r} \sin(\omega t - kr + \alpha) \quad (1)$$

where r is the radial coordinate, A is the amplitude of spherical wave having the frequency $f = \omega / 2\pi$ which propagates from the source with the speed c and $k = \omega / c$ is the wave number.

In the case when the sound propagates by cylindrical waves traveling uniformly, the acoustical pressure can be written [3]:

$$p = A\left[J_0(kr) + iY_0(kr)\right]e^{-i\omega t} \quad (2)$$

where r is the cylindrical coordinate, A is a constant, J_0 is the Bessel function of the first degree and zero order and Y_0 is the Bessel-Neumann function of the second degree and zero order. In the same way, taking into account that the propagation of the perturbation can happen under the form of plane waves and considering only the case of divergent wave, the acoustic pressure in a point of the acoustical field is given by [3]:

$$p = \rho_0 \omega A \sin(\omega t - kx + \varphi) \quad (3)$$

Propagation of spherical, cylindrical and plane waves is characterized by the variation of the acoustic pressure in a specific point of the acoustic field. The acoustic pressure in a point of the field is obtained by adding the acoustic pressures corresponding to each type of wave.

The sound pressure level in a point of the acoustic field is given by the expression:

$$L = 20 \lg \frac{p}{p_0} \quad (4)$$

where p is the acoustical pressure in a point of the acoustic field and p_0 is the reference acoustic pressure $p_0 = 2 \cdot 10^{-5} [N/m^2]$.

Using the instantaneous acoustic pressure one can compute the instantaneous sound pressure level defined by Eq.(4) and the equivalent acoustic level of sound corresponding to an equivalent intensity which would be constant during the whole period of time and it is defined by:

$$L_{Aeq,T} = 10 \lg \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p_A^2}{p_0^2} dt \right] \quad (5)$$

where $L_{Aeq,T}$ is the continuous equivalent acoustic pressure level A-weighted, measured in dB, determined in a time interval which starts at t_1 and ends at t_2, p_0 is the reference acoustic pressure and $p_A(t)$ is the weighted instantaneous pressure of the acoustic signal.

Effectively, the equivalent acoustic level can be obtained through computations using Eq.(5) or directly by measurements, using for instance the Bruel&Kjaer 2250 Analyzer, which allows measurement and recording of many characteristic parameters of the sound as well as the spectral analysis in frequency bands of 1/1 or 1/3 octave and also the statistical distribution of the noise level.

The noise generated by sources from the road transportation means is extremely injurious for human being's nervous system generating psycho-physiological and blood circulation modifications as well as sleep disturbances. Moreover, the visual function and endocrine gland are adversely affected. At the same time, the noise generates auditory tiredness and sonorous trauma.

In order to reduce the effects of the noise, limit values which cannot be exceeded are established. These limits are characterized by equivalent noise level defined by Eq.(5) and by the noise curves (C_z). The noise curves C_z define the relation between the characteristic frequency of a sound and the proper acoustic pressure level in the conditions of a subjective equivalent sensitivity.

In this respect, the Romanian standard STAS 10009-88, "Urban Acoustics" established the admissible limits of the noise level in urban environment, differentiated on zones and functional endorsements, technical category of streets established on the basis of the technical settlements.

In case of noise levels generated by transportation means on road thoroughfares, the admissible limits are presented in table 1. In the same time, the disposition of buildings on the streets of different technical types and also the road traffic organization must be done so that be assured the admissible limits for the street exterior noise level established in accordance with STAS 10009-88 to 50 dB measured at 2 m distance from the building, respectively the C_z45 curve.

Table 1 *Admissible nloise levels*

Street types (according to STAS 10144-80)	L_{eq} [dB]	C_z [dB]	L_{10} [dB]
I-main	75-85	70-80	85-95
II-linking	70	65	75
III-collecting	65	60	75
IV-local serving	60	55	70

Taking into consideration that the acoustic field generated by the road transportation means is extremely complex, its study it is recommended to be experimentally performed.

4. MEASUREMENT ACCOMPLISHMENT AND ANALYSIS OF RESULTS

Noise level measurements were performed in 62 measurement points which were located near some of the most important crossings from Timişoara City [5], [6]. The measurements were performed using noise analyzers which allowed recording the most important parameters of the noise, such as L_{eq} (equivalent noise level), L_{AE} (exposure level), L_{max} (maximum noise level) L_{min} (minimum noise level), $L_{0.1}$, L_5, L_{10}, L_{50}, L_{90}, L_{95} (percentage noise levels), which were determined during a continuous period of 8 hours (7.30-15.30). The microphone was placed next to the street's border at 7.5 m distance from the axis of the first runway, at 1.3 m high from the ground.

Simultaneously with noise data recording, the traffic composition and intensity as well as the speed of the vehicles were determined. The results of measurements as well as the intensity and composition of the traffic were centralized in a data base designed from the study of phonic pollution generated by the road transportation means in Timişoara City.

Table 2 *Statistical distribution of the noise*

L_{eq} [dB]	No. of points	%	% of disturbed people
{54.3}	1	1.6	8
[55;60]	0	0	0
[60.3;64.6]	6	9.7	[25;41]
[65.2;70]	20	32.3	[42;60]
[70.1;74.9]	24	38.2	[60.1;79.9]
[75.1;79.5]	8	12.9	[80.1;97.9]
{81.8}	1	1.6	100
[85.5;85.9]	2	3.2	100

From the obtained data it results that in 46 measurement points (from a total of 62 points) which means 74.19% of the measurement points, the equivalent noise level exceeds the maximum admissible value defined by the Romanian standard STAS 10009-88 concerning "Urban Acoustics". The overtaking was within the interval 0.1-16.1 dB. Table 2 presents the statistical distribution of the equivalent noise level (L_{eq}) in the measured points, as well as the percentage of disturbed people [7]. Fig.1 shows a chart of the percentage of equivalent noise levels recorded in the measured points.

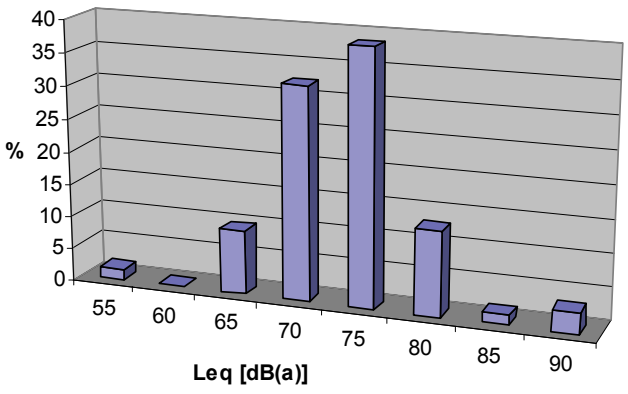


Fig. 1 *Percentage of noise levels in the measured points*

In these considered points, the admissible noise level established to 50 dB(A) measured at 2 meters distance from the buildings was generally exceeded with 1.3-32.9 dB(A). The traffic intensity ranged between 9 and 2681 aut/h while the speed of vehicles ranged between 50 and 60 km/h. The percentage of different transportation means is presented in table 3.

Table 3 *Road traffic composition*

Transportation Means	Minimum %	Maximum %
Buses	0.03	3.78
Trolleybuses	0.1	7.8
Microbuses	3.5	9.5
Cars	72.9	95.27
Trucks	0.3	17.9
Tractors	0.01	1.3
Motorcycles	0.06	3.0

5. MEASURES FOR NOISE DECREASING

In order to reduce the noise generated by the road transportation means in Timişoara City, some measures intended to noise decreasing were established and implemented. On many streets the superstructure of the runway was improved. Many crossings were modernised and semaphores were installed. One-way traffic was imposed for some road thoroughfares, the speed of vehicles was limited and on many streets were installed speed limiters. It was eliminated the presence in traffic of heavy trucks in the central area of the City. In some areas it was allowed the access only for certain categories of vehicles. Between the runways and the residential areas protective green zones were planted. In the N-E of the City was activated the ring road, which re-direct the heavy traffic in this direction.

The effect of the implementation of these measures for noise reduction were evaluated through new measurements performed in 9 measurement points, selected near some of the most important crossings from Timişoara. From the obtained data it results that in the 9 points, the equivalent noise level was reduced with 0,1-9,4 dB and in 5 points (55,5%) the noise level does not exceed the admissible value defined by STAS 10009-88. The average equivalent noise level in these 9 considered points was of 72.02 dB(A) for an average traffic intensity of 1595.6 aut/h before the application of the noise abatement methods and 67.84 dB(A) for an average traffic intensity of 1712.8 aut/h after the implementation. Regarding the average equivalent noise level existent at 2 meters distance from the buildings, this one was of 65.6 dB(A) before the application of noise abatement methods and 62.7 dB after that. The percentage of road transportation means in these 9 measured points ranged between 0.02 (tractors) and 95.27 (cars) before the application of the noise abatement methods and respectively 0.1 (tractors) and 93.6 (cars) after the application of the noise abatement methods.

Analysing these data one can conclude that by implementing the proposed decreasing methods for the noise generated by the road transportation means in Timişoara City it was obtained indeed a decreasing of the noise levels, but the admissible limits established by STAS 10009-88 are still exceeded. In this case, other acoustical arrangements of the thoroughfares are needed to be established and implemented in order to diminish further the noise generated by transportation means.

Therefore, taking account that an important contribution to the noise generated by the road transportation means on the road thoroughfares has the contact between the tire and the rolling surface, this can be reduced by covering the road thoroughfares with rubberized asphalt or with rubber pavement. Using these acoustical arrangements it is obtained a reduction of the noise level with an average of at least 4 dB. Rubberized asphalt consists of regular asphalt mixed with crumb rubber obtained from used tires that would otherwise be discarded or take up space in landfills.

Using a kind of passive protection measure against the noise, acoustical screens can be installed between the runways and the residential areas. In this way, it was started the assembling of the acoustical screens between the runways and the residential areas in the penetration zones of Timişoara City. One of them was assembled between the runway and the school. The screen is made of Plexiglas and has the dimension 40x3x0.02 m. It was assembled at 9.5 m distance from the axis of the first runway. The effect of this screen on noise abatement can be observed in figs. 2 and 3 where are presented the frequency spectra obtained in a measurement point at 7.5 m distance from the axis of the first runway and 2 m distance before the screen (fig.2), respectively in a measurement point located at 12 meters behind the screen (fig.3).

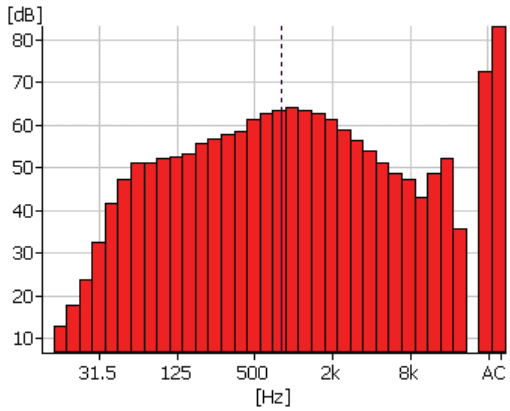


Fig. 2 *A-weighted frequency spectra at 2 m distance before the screen*

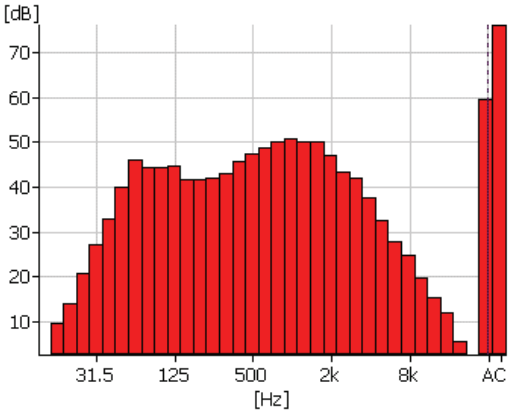


Fig. 3 *A-weighted frequency spectra at 12 m distance behind the screen*

The traffic intensity in these measurement points was of 1904 aut/h and the percentual traffic composition was: buses 0.5%, trolleybuses 0.7%, microbuses 7.6%, cars 81.3%, trucks 9.7% and motorcycles 0.2%. In the same time the speed of vehicles ranged between 50 and 60 km/h.

One can be observed the effectiveness of the acoustical screen in decreasing the noise generated by the road transportation means, in our case for Timişoara City.

6. CONCLUSIONS

After performing the investigations described in the paper, it was possible to evaluate the degree of phonic pollution generated by road transportation means in Timişoara City. The implementation of the noise decreasing measures in urban area leads to diminution of the noise level and a diminution of the percentage of disturbed people. The measurements performed after the implementation of the noise decreasing measures in urban area emphasize its efficiency. Once the implemented measures proved their efficiency, they can be applied in every practical situation concerning traffic or industrial noise.

As it results from this work, one can conclude that the noise decreasing measures implemented in Timişoara City proved their efficiency.

The alignment to European regulations imply yet the application of the Directive 2002/49/EC concerning the management of the environmental noise, this one needing beside noise mapping, a permanent monitoring of the noise in real conditions by real measurements.

REFERENCES

[1] A. Stan et al. "Consideraţii asupra nivelului intensităţii zgomotului de traffic în exteriorul clădirilor din zona centrală şi semicentrală a municipiului Bucureşti", *Construcţii*, nr.10, 1973

[2] M. Grumăzescu et al., *Combaterea zgomotului şi vibraţiilor în tehnică*, Bucureşti: Ed. Tehnică, 1964

[3] N. Enescu, I. Magheţi, M.A. Sârbu, *Acustică Tehnică*, Bucureşti: Ed. ICPE, 1998

[4] E.Ia. Iudin, *Izolarea împotriva zgomotelor*, Bucureşti: Ed. Tehnică, 1968

[5] N. Herişanu, V. Bacria, M. Toader, S. Popa-Radovan, "Investigation of noise pollution in an urban area", *WSEAS Transaction of Systems*, 7(5), p.1642, 2006

[6] V. Bacria, N. Herişanu, Acoustical arrangement of the road superstructure, *Proc. of the Seventh Trienal International Conference Heavy Machinery* HM2011, Vranjacka Banja, 2001

[7] *** *Lärmbekamfung in Wien, Enwicklung Stand Tendenzen*. Magistratsabteilung 22 Umweltschutz.

University of Nis
Faculty of Occupational Safety

„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

ACOUSTIC TESTING INSIDE CABIN AND PASSENGER SPACE OF OFF-ROAD VEHICLE LAND ROVER DEFENDER 110 SOFT TOP

Aleksandar Mićović[1], Vladimir Popović[2], Snežana Jovanović [1]

[1] Technical Test Center Belgrad, Vojvode Stepe 445, 11000 Belgrade, e-mail: toc@toc.vs.rs.
[2] Faculty of Mechanical Engineering, University in Belgrade, Kraljice Marije 16, 11120 Belgrade

Abstract - *The development of automobile industry and rapid increase of competition in the vehicle market imposes ever increasing obligation to the manufacturers to meet ever more complex demands of the users regarding economic quality, comfort, safety as well as environmental protection.*

The influence of noise and vibrations on man has been studied in both exploitation and laboratory surroundings. It should be said that laboratory research has been in focus much more since it provided for the stable parameters of micro-environment and repeatability of results. It should also be mentioned that the research of this type in real exploitation conditions are much more expensive and far more complicated when it comes to comparison of measuring results. Considering that within the final testing of prototypes of certain vehicles for the requirements of the Serbian Army the conditions have been created to carry out this type of measurement as well, we have been given a unique opportunity to monitor the above said parameters of comfort in the course of intensive driving of off-road vehicles along three types of test tracks:

- *broken ground (Deliblatska Peščara),*
- *lowlands and upland macadam (Fruška gora, Zlatibor), and*
- *asphalt ground.*

Taking into account the continuous intensification of strictness of world standard quality requirements which define vibrations (human and structural) and noise, measurements and analyses of vehicle noise and vibrations take over the role of the prime-mover of the development and modification of the systems which are in operational use. The paper presents the results of measuring noise inside the cabin and passenger space of Land Rover Defender 110 Soft Top off-road vehicle under real exploitation conditions.

Key words: noise, cabin, off-road vehicle, comfort

1. INTRODUCTION

Testing of randomly sampled Land Rover Defender 110 GS Soft Top off-road vehicle was carried out by the Technical Test Center in Belgrade. An up-to-date 4-cylinder turbo chared intercooled Diesel engine is built in the vehicle. The engine is manufactured by Ford and belongs to *Duratorq-DI* generation. It is equipped with two camshafts and four valves per cylinder respectively. The camshaft drive is over the chain, which is also used for high-pressure pump drive. Fuel injection is carried out by Common Rail system. Maximum vehicle length (with/without bumpers) is 4578/4439 mm, while the maximum width (with wing mirrors) (SAE W104) is 1992 mm. Empty vehicle with full fuel tank weighs 1888 kg. The allowed total weight of a loaded vehicle (GVW) is 3500 kg.



Figure 1 *Land Rover Defender 110 GS Soft Top*

2. MEASURING CONDITIONS

Comfort testing inside the cabin in terms of the nose level was carried out while driving on the asphalt surface according to ISO 5128. The level of sound pressure inside motor vehicles is generally greatly influenced by microtexture and coarseness of the testing path surface, the smooth road surface producing acoustically more steady internal levels. Regardless of the fact that specified procedures of the standard are not intended for the evaluation of exposure to noise in terms of comfort and safety, such as fatigue and vigilance, the basic motive of the testers was to achieve the defined and unified measuring conditions which would enable to compare and repeat the testing results. In addition to this, it is important to note that present state-of-affairs of the adopted international standards in the field still do not allow good correlation between the measured data, on the one hand and comfort and safety on the other, and that the acoustic measurement results inside the vehicle according to ISO 5128 is the most similar to the real life conditions.

There was also the additional acoustic measurement inside the vehicle in the situation when the vehicle was driven on the macadam road in accordance with the Directive 2003/10/EC – noise on the minimum health and safety requirements regarding the exposure of workers to the

risks arising from physical agents (noise) (Seventeenth individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC). Since the basic purpose of the vehicle is driving along various terrains and off-road conditions, we were interested in establishing or evaluating the risk to hearing of test drivers, who were involved in intensive test drives for a relatively short period of time (two months).

The measurements were carried out by Vibro-acoustic Measuring System NetdB12 (01dB Metravib) by Areva French manufacturer. At the same time two microphones were set by means of special adapters on the heads of both the driver and passengers.



Figure 2 *Vibro-acoustic Measuring System NetdB12*

"Fast" dynamic characteristic and "A" frequency setting of sound pressure were chosen for the measurement. The weather conditions were within standard limits (in terms of humidity, temperature and wind). Ambient noise was considerably below 10 dB in comparison to the cabin, so that there were not subsequent corrections of the results. Inside the vehicle the seats of the driver, codriver and one passenger were occupied in the course of measurment. Special attention was paid to vehicle preparation. The tyres mounted according to the manufacturer's specification were almost new (they were driven for 450 km only), with 2.1 bar pressure respectively. Before the measurment started, the engine was stabilized at the normal operating temperature and the tank was filled with fuel. All windows and ventilation outlets were closed, since their contribution to the total level of noise inside vehicle was not a part of this testing.

The first part of testing refered to the measurment of maximum vehicle speed so that in the second stage it was possible to determine speed regime of the vehicle during which the internal noise would be measured (the regime of stable speed and the regime of full acceleration ISO 5128). The measurment was made by Corrsys-Datron non-contact unit with Correvit L-350 Aqua optical sensor.

This device is intended for comprehensive measurement of dynamic characteristics of a vehicle such as: current speed, current acceleration, distance and testing period. Its basic characteristics are as follows:

- working range: from 0.3 to 250 km/h
- measurement accuracy: more than 0.1%
- working distance and range: 350 ± 130 mm
- measurement speed: up to 250 data per second
- distance resolution: 1.5 mm
- digital output range: from 1 to 1000 impulses
- analogue output range: from 0 to 10 V

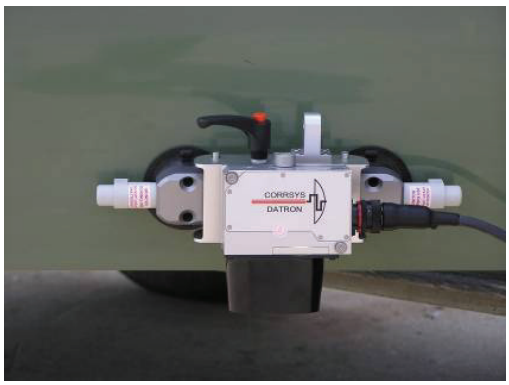


Figure 3 *Corrsys – Datron Correvit L-350 Aqua*

The measurements were carried out at airport runway in Kovin and on a part of Belgrade-Šid highway. The measured maximum speeds at certain gears corresponded to speeds specified by the manufacturer and are presented in Table 1.

Table 1 *Max. speeds of the vehicle in respective gears*

Gear	Max speed (with reduction turned off) (km/h)/ mph	Max speed (with reduction turned on) (km/h)/ mph
1.	10.64 (6.61)	28.73 (17.85)
2.	20.4 (12.68)	55.06 (34.22)
3.	33.65 (20.91)	90.84 (56.45)
4.	47.35 (29.42)	127.83 (79.43)
5.	57.92 (35.99)	132 (82)
6.	77.96 (48.43)	132 (82)

In order to define engine working mode when testing the full acceleration, we have compared the measured vehicle speed values with the manufacturer-specified engine values:

- number of engine rotations at max. output – 3500 rpm
- max. output (EEC) – 90 kW
- number of engine rotations at max. moment – 2000 rpm
- max. output (EEC) – 360 Nm
- outside noise of a passing vehicle – 73 dB.

We have concluded from the above stated that the starting stable speed in V gear at 1575 rpm (45% from the number of rotations at which the engine reaches maximum output) is about 55 km/h. The vehicle speed at 3150 rpm (90% from the number of rotations at which the motor reaches its maximum output) in V gear is about 115 km/h.

3. MEASUREMENT RESULTS

Simultaneous acoustic measurements on both the driver's (measuring point MM1) and passenger (MM2) seats respectively were carried out in the course of driving on asphalt base with the windows closed, in two cycles:

- At stable speed ranging from 53 km/h (40% v_{max}) to 106 km/h (80% $v_{max.}$), V gear;
- At the acceleration from 55 km/h to 115 km/h, which was also V gear.

Several measurements were made on macadam road at constant speeds which corresponded to previously determined average vehicle speeds at this type of surface (30-50 km/h), and with and without heating and ventilation

cooler turned on in the cabin. The measurements were repeated several times on all surfaces, but due to extensive results we have decided to present only some equivalent levels of noise in dB(A) at Figures 4 to 7 and in Table 2, with the described minimum, maximum and observed period.

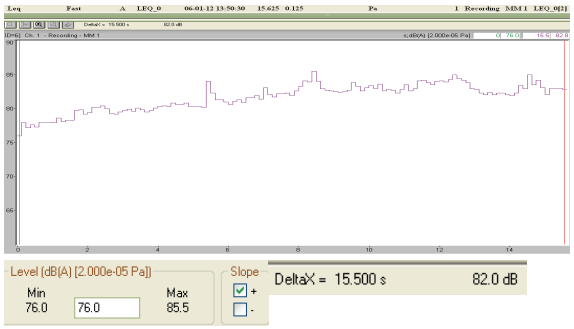


Figure 4 *Noise at measurement point – driver, measured during driving at the acceleration from 5 to 115 km/h*

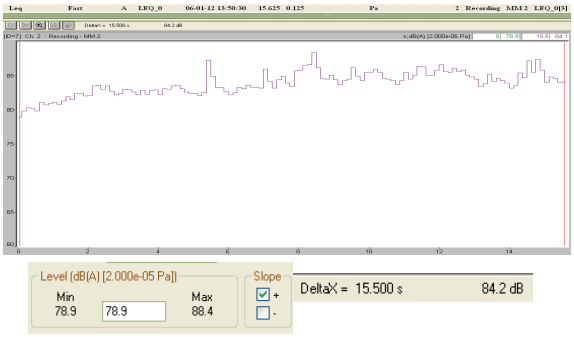


Figure 5 *Noise at measurement point – passenger sitting on the right bench in cargo area, at the acceleration from 55 to 115 km/h*

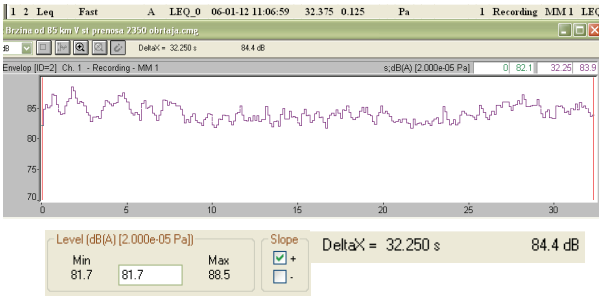


Figure 6 *Noise measured at the driver's seat at stable speed of 85 km/h, on asphalt base, for a longer measuring period*

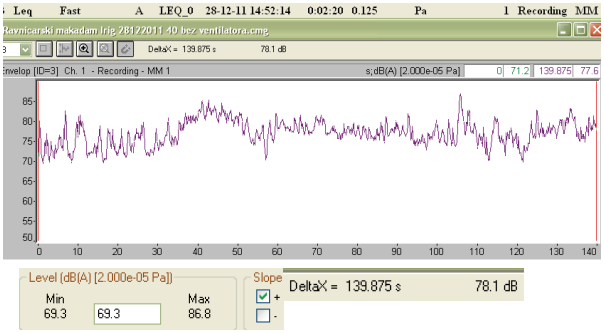


Figure 7 *Noise measured at the driver's seat at stable speed of 40 km/h at macadam road*

Table 2 *The results of measured levels of noise*

	Measuring point	Noise level, L_{eq} (dB(A))		Measuring period, period of exposure (sec)
		driver	passengers	
(km/h)/(rpm)	**Stable speeds on asphalt base, in V gear**			
53/ 1500		**69.9**	**71.5**	**16.5**
65/ 1750		**72.3**	**74.4**	**17.5**
75/ 2050		**74.4**	**77.1**	**18.5**
85/ 2350		**77.2**	**80.3**	**17.5**
95/ 2550		**79.1**	**81.8**	**17.3**
106/ 2900		**82.7**	**84.6**	**17.1**
Stable speed of 40 km/h on lowlands macadam road				
Without ventilator		**78.1**	**77.6**	**140**
With ventilator turned on		**79.6**	**79.4**	**75**
Acceleration 55 ÷ 115 km/h, i.e. up to 3.150 rpm, V gear on asphalt base				
		82		**15.5**
	Passengers on the left		**83.7**	**23.375**
	Passengers on the right		**84.2**	**15.5**

3. CONCLUSION

The analysis of all measured levels of noise suggests that the value exceeds 76 dB(A), except in case of driving on the asphalt base at stable speed of 75 km/h. It is obvious that noise is higher on passenger seats inside the vehicle. Based on the measuring results of the level of internal noise, this type of vehicle can be classified as quite a noisy vehicle.

REFERENCES

[1] A. Mićović, "Unutrašnja buka traktora CLAAS 55 kao faktor komfornosti", *Traktori i pogonske mašine*, vol. 6, pp. 60-64, 2001.

[2] ISO 5128:1980 (E) - Acoustics - Measurement of noise inside motor vehicles

[3] *SRPS 0031* - Karakteristike komfornosti vojnih vozila, ispitivanje unutrašnje buke



University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

ANALYSIS OF THE NOISE FROM RAILWAY TRAFFIC

Sandra Šaković [1], Predrag Petronijević [2], Milovan Stanojev [2]

[1]University of Niš, High Technical School, sandrasakovic@hotmail.com
[2] University of Niš, the Faculty of Civil Engineering and Architecture

Abstract - *In this paper are analyzed the measures for controlling of the noise level of railway traffic in the phase of usage of the railway as civil engineering infrastructure. The various influences are analyzed such as the separation of passenger and freight subsystems in the railway node and position of the route relative to terrain, state of the super and sub structure regarding the noise emission. It is indicated that the effective solution of the problem of noise is that one which is based on clearly defined legal regulations and technical standards.*

Ecological principles of environmental protection in the civil engineering, with respect to line structures, are included in "The study of the assessment of impact of modernization of the railway Belgrade (Batajnica)-Stara Pazova-Šid-Croatian border on the environment", from the view of traffic noise and vibration, and implementation of appropriate measures of protection in construction and operation phase.

1. INTRODUCTION

The Republic of Serbia which signed the Kyoto Protocol in 1997, obliged to reduce traffic pollution gasses emission. Such transportation policy increase the competitiveness of railway in comparison to other kinds of traffic, but the negative noise effect in the surrounding of railway infrastructure is expected. The European transportation policy plans to triple the passenger traffic by railway by 2020 and thus reduce air pollution and increase road safety, but also that the noise will increase by 30 dB 0.

By measuring and analysis of the railway noise in the widest range of velocities used in operation, it was determined that the biggest problem is posed by the noise generated at the contact of the wheel and the rail [2]. At low speed range, the noise generated by the vehicle drivetrain is prominent. At higher speeds, the noise of the wheels rolling on rails, and of the drag become prominent. The drag noise depends on the aerodynamic design of the vehicle. The noise level primarily depends on the surface at the contact of the wheel and the rail and the speed of the vehicle (figure 1). The vehicle and rails maintenance have significant effects on the noise level. The rolling of the wheels on the rail generates noise for the following reasons:

- Condition of contact surfaces of wheels and rails
- Abrupt changes of rigidity along the rails with discrete support of the sleepers
- Influence of rail joints (mechanical with joining devices, insulated, welded),
- Rolling and friction of the wheel treads against the side of the head of outer rail in a curve.

The noise generated by the passenger of railway traffic, represents a significant influence on the environment. The regulations on the level of noise in a settled environment (official Gazette of RS, no. 54/92) proscribes the maximum allowed levels of noise along major routes to be 65dB by day and 55 dB by night.

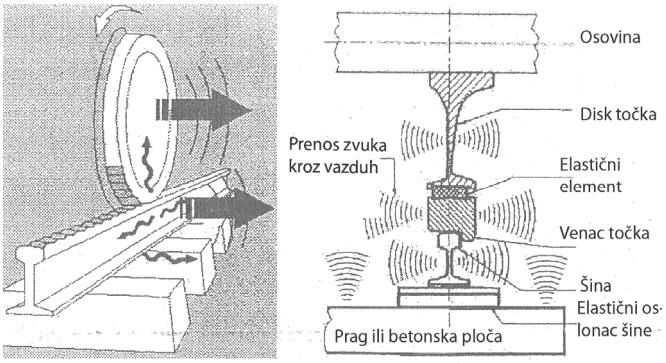


Fig: 1 *Principle of noise generation at the contact of a tread and rail 0,[2]*

2. THE CURRENT LEVEL OF TRAFFIC NOISE IN THE AFFECTED ZONE

Calculated noise level values

Lacking the measured values of the measured level of noise in the corridor of the railway line: Belgrade-Batajnica-Stara Pazova-Šid-border with Croatia, due to the railway traffic, the model „Richtlinien zur Berecnung der Schallmmissionen von Schinennjegen, Schall 03“ [3] was implemented. The calculation of the simulation of the noise level in the observed corridor as the effect of railway traffic was done, for the return period until 2030, with the planned traffic load, designed train speeds of 120 km/h [4] and following values were obtained [5], [6].

Table: 1 *Calculated values of the existing noise levels on the railway line sections*

Profile number 1-1, Section: Batajnica-Nova Pazova, Mile mark km 23+608.80													
Profile to the left of the tracks							Profile to the right of the tracks						
Level in dB	Distance from the tracks (m)						Level in dB	Distance from the tracks (m)					
	25	50	75	100	150	200		25	50	75	100	150	200
Day	68.5	64.2	62.5	61.4	58.7	57.8	Day	68.5	63.7	62.8	62.2	59.4	58.4
Night	67.5	63.1	61.5	60.4	57.7	56.8	Night	67.5	62.7	61.8	61.2	58.4	57.5
Profile number 4-4, Section: Golubovci-Ruma, Mile mark km 50+255.10													
Profile to the left of the tracks							Profile to the right of the tracks						
Level in dB	Distance from the tracks (m)						Level in dB	Distance from the tracks (m)					
	25	50	75	100	150	200		25	50	75	100	150	200
Day	65.4	61.7	60.1	59.0	57.0	55.2	Day	65.4	61.1	59.5	58.3	56.4	54.6
Night	65.2	61.4	59.9	58.7	56.7	54.9	Night	65.2	661.4	59.9	58.8	56.9	55.0
Profile number 5-5, Section Ruma-S. Mitrovica, Mile mark km 75+043.91													
Profile to the left of the tracks							Profile to the right of the tracks						
Level in dB	Distance from the tracks (m)						Level in dB	Distance from the tracks (m)					
	25	50	75	100	150	200		25	50	75	100	150	200
Day	64.4	60.7	59.1	58.0	56.0	54.2	Day	64.4	64.7	59.1	58.0	56.0	54.2
Night	65.7	62.0	60.4	59.3	57.3	55.5	Night	65.7	62.0	60.4	59.3	57.3	55.5
Proifle number 6-6, Section: S. Mitrovica-Šid, Mile mark km 113+886.61													
Profile to the left of the tracks							Profile to the right of the tracks						
Level in dB	Distance from the tracks (m)						Level in dB	Distance from the tracks (m)					
	25	50	75	100	150	200		25	50	75	100	150	200
Day	64.8	61.1	59.5	58.3	56.4	54.6	Day	64.8	61.1	59.5	58.3	56.4	54.6
Night	65.3	61.6	60.0	58.8	65.9	55.0	Night	65.3	61.6	60.0	58.8	56.9	55.0

On the basis of the calcualted values of the noise levels in the corresponding cross sections of the existing tracks and the permissible values of railway noise in a settlement, it can be noticed that the permissible values of the noise level occur at the distance of 25 to 100 m from the track axis on the left side during day and 140 to 450 m during night, and on the right side at the distance 25 to 45 m during day and from 45 to 1050 m during night. In the stations, the levels of noise are below the limit values during day on both sides of the tacsk, and during night, the limit values are reached at a distance from 45 to 85 m.

Influence of the traffic noise and vibrations on the environment

Traffic noise

In the observed railway corridor, considered for the environment damage by the traffic, there is a modernized railway: Belgrade (Batajnica)-Stara Pazova-Šid- border with Croatia. Implementing the model „Richtlinien zur Berecnung der Schallmmissionen von Schinennjegen, Schall 03“ [3] a calculation of the simulation of the noise level in the observed corridor as the effect of railway traffic was done, for the return period until 2030, with the planned traffic load, designed train speeds of 120 km/h [4].

Traffic noise protection measures

By comparing the results of calculation of noise levels as the effect of railway traffic (Table 1) with the permissible noise levels in settlements in the design period until, 2030, the simulated values of the noise level Table 2, of the same cross sections of the modernized railway tracks, the following conclusions can be drawn:

- In the stations, the limit values of the noise level on both sides of the rack are not reached, and in the night period, they are reached at a distance of about 30 m on both sides of the track.
- On the open track, the limit values of noise level during the day on the left hand side of the track are reached at a distance from 45 to 400 m and from 300 to 600 m during the night, and during daytime at a distance of 50 to 720 m and during night from 300 to 920 m.

As a noise protection measure, it is proposed to ban building housing buildings along the tracks within the mentioned corridors. Installing double windows on the housing buildings which are within distance of 30m from the axis of

the tracks in the station area, [8], [8]. A buffer of protective greenery along the tracks can form noise protection barrier.

Table: 2 *Simulated values of noise levels throughout the design period (up to 2030) on the railway line sections*

Profile number 1-1, Section : Batajnica-Nova Pazova, Mile mark km 23+608.80													
Profile to the left of the tracks							Profile to the right of the tracks						
Level in dB	Distance from the tracks (m)						Nivo u dB	Distance from the tracks (m)					
	25	50	75	100	150	200		25	50	75	100	150	200
Day	74.3	69.9	68.3	67.1	64.4	63.6	Day	74.3	69.4	68.5	68.0	65.1	64.3
Night	73.2	68.8	67.2	66.0	63.4	62.5	Night	73.2	68.4	67.4	66.9	64.1	63.3
Profile number 4-4, Section : Golubovci-Ruma, Mile mark km 50+255.10													
Profile to the left of the tracks							Profile to the right of the tracks						
Level in dB	Distance from the tracks (m)						Level in dB	Distance from the tracks (m)					
	25	50	75	100	150	200		25	50	75	100	150	200
Day	70.3	66.6	65.0	63.8	61.9	60.1	Day	70.3	66.6	65.0	63.8	61.9	60.1
Night	69.7	65.9	64.4	63.2	61.2	59.4	Night	69.7	65.9	64.4	63.2	61.2	59.4
Profile number 5-5, Section Ruma-S. Mitrovica, Mile mark km 75+043.91													
Profile to the left of the tracks							Profile to the right of the tracks						
Level in dB	Distance from the tracks (m)						Level in dB	Distance from the tracks (m)					
	25	50	75	100	150	200		25	50	75	100	150	200
Day	69.0	65.3	63.7	62.6	60.6	58.8	Day	69.0	65.3	63.7	62.6	60.6	58.8
Night	70.3	66.6	65.0	63.8	61.9	60.0	Night	70.3	66.6	65.0	63.8	61.9	60.0
Profile number 6-6, Section : S. Mitrovica-Šid, Mile mark km 113+886.61													
Profile to the left of the tracks							Profile to the right of the tracks						
Level in dB	Distance from the tracks (m)						Level in dB	Distance from the tracks (m)					
	25	50	75	100	150	200		25	50	75	100	150	200
Day	68.9	65.2	63.6	62.5	60.5	58.7	Day	68.9	65.2	63.6	62.5	60.5	58.7
Night	70.4	66.7	65.1	64.0	62.0	60.2	Night	70.4	66.7	65.1	64.0	62.0	60.2

3. NOISE CONTROL IN ALL THE PHASES OF RAILWAY INFRASTRUCTURE

Development policy of contemporary European railway comprises control of possible harmful effects on the environment in the planning, designing, building and maintenance phases of railway infrastructure. Harmful effect of noise and vibrations of the railway traffic is analyzed in respect to the zones for rest, recreation, dwelling and work of the population. The environmental effect of railway systems on the environment, from the standpoint of engineering infrastructure is primarily defined:

- By the adopted concept of separation of passenger from freight subsystems in area of traffic and railway intersections,
- By the choice of spatial position of routes of railway passenger subsystem and passenger terminals in relation to the elevation of terrain in urban environment,
- By the geometrical shaping of the route (spatial macro-geometry of the tracks),
- By the choice of railway superstructure and substructure,

Introduction of contemporary passenger terminals in the central zones of the city requires minimization of environmental influences of railway traffic on the urban environment. By separation of freight subsystem (tracks and offices intended for freight transport) outside the urban area of traffic intersection contributes the most to reduction of negative impact of railway traffic noise on the population. For this reason, new railway terminals of transitional type, are organized vertically so as to occupy as smaller surface area of municipal land, and to place the largest noise sources below ground. The principle of transmitting the railway noise on the surrounding structures is presented in Figure 2

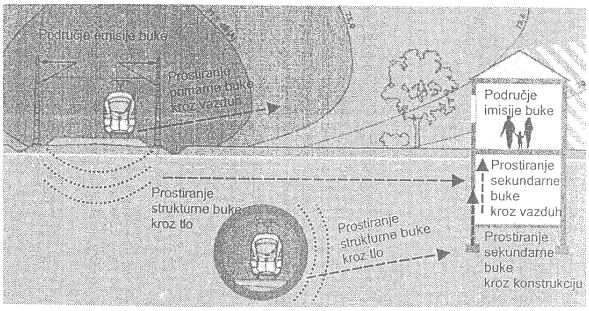


Fig: 2 *The principle of transmitting the railway traffic noise on the surrounding structures [2]*

By the proper choice of the elements of route geometry, in the plan (radii of horizontal curves, shape and length of transition curves, lengths of straights) and longitudinal profile (level gradients, shape of the ramps for elevation of the outer rail in a curve, position of the level transitions, radii of vertical rounding) expected extent and type of activities and maintenance costs during operation can be defined. This is important, since any irregularity in geometry of the tracks increases emission of noise when the vehicles travel along the tracks.

After defining the spatial arrangement and geometrical formation of the route, the level of environmental impacts on the environment is primarily defined by the design of super and sub structure of the railway. In operation, the noise level and vibrations emitted off the tracks must be retained within designed parameters.

Also, the structure of the superstructure must meet the sitting or standing passenger comfort demands, with minimum negative impact, and if possible with positive impact on the environmental relationships [10], [10]

The usage of machinery for maintenance of the tracks on the crushed stone ballast is favorable, from the point of view of efficiency and extremely unfavorable from the aspect of noise emission. The conditions for operation of machinery is extremely difficult to realize in the conditions comprising intensive traffic, confined working space (tracks between the platforms, devices and equipment built in the tracks). S a consequence it is often not possible to use machinery to maintain the tracks, so unreliable, long lasting and inhuman manual labor is required.

Reduction of noise and vibration emission is achieved by applying the system of elastic rail fixings [9,10], by reducing the distance between the sleepers (not exceeding 60 cm), by installing elastic elements under the sleepers (elastic mats or "coated" sleepers) and elastic subgrade under the ballast layer.

In general, the level of noise emitted by the vehicle passing along the tracks on hard subgrade (without additional noise protection measures) is 5 dB(A) higher in comparison to the tracks on the ballast layer. Notwithstanding, the minimum maintenance costs, which are reduced to inspection and care, as well as long service life of the structure make this design advantageous in an urban environment [8], [10]. The designs of the tracks with continuously elastically supported tracks over a hard subgrade have a lower noise emission in comparison to the structures with discretely elastically supported tracks. Apart from the standard additional measures of noise-proofing, there are also the prefabricated elements for noise absorption which can be installed n the tracks on the hard surface, or turf cover [9],[10], [10]. As a special type of tracks on hard surface in shallow tunnels, or under the buildings sensitive to structural noise and vibrations, there are systems with massive shock-dampening concrete slabs.

4. MEASURES FOR NOISE CONTROL AT THE CONTACT OF TREADS AND RAILS

Analyzing the expressions of the level of noise emission (1) according to [12], it can be concluded that control of noise at the contact of the treads and rails requires conducting of appropriate measures in design and maintenance of vehicles and tracks, and traffic organization measures:

$$L_{mE} = 10 \lg\left[\sum 10^{0.1(51+D_{Fz}+D_D+D_l+D_V)}\right] + D_{Fb} + D_{Br} + D_{Bue} + D_{Ra} \quad (1)$$

Where: 51 dB – is the basic value of the noise emission level, D_{Fz} – vehicle type impact, D_D – brake type impact, D_l, - vehicle length impact, D_V- vehicle speed impact, D_{Rb} – design and condition of tracks impact, D_{Br} – bridge impact, D_{Bue} – junction with roads at grade impact, D_{Ra} – impact of tracks in curves.

The structural measures for reduction of track wrinkling is either continuous support of rails or reduction of distance of discrete supports (sleepers spacing <60cm, which increases the rigid resistance to bending) and reduces the rigidity of the system of direct fixation of the rails (the recommended static rigidity of the rail element is up to 200kN/cm). The practice has shown that there are no wrinkling effects in the continuously supported rail, or they occur later than in respect to discretely supported rails.

Wrinkling of the rail head is tackled by grinding [3]. In the world, rail grinding (and lubrication of the outer rail in curves) is a routine part of rail maintenance. The timely grinding of surface irregularities prevents their further propagation. Grinding effect is not permanent, it must be repeated cyclically as the wrinkling reappears.

When removing the material by grinding, the transverse profile of the rail must be retained, in order to keep the stresses at the contact of the wheel and the rail within permissible limit and thus provide the stable ride.

A common cause to irregularities on the wheel web is the damage caused by applying brakes on the wheels. The damage level is in direct proportion with the design of the brake as seen in the expression (1). Disk brakes do not damage the wheel web, and thus contributed to noise level reduction to 11 dB (A) in respect to the brake with cast iron shoe brakes [10], [10].

5. CONCLUSION

For efficient railway traffic noise management it is necessary to have cooperation and joint strategy of vehicle and railway infrastructure maintenance. This is a serious task, due to the negative effects of noise on human health, quality of live and productivity. The problem cannot be solved by appeals to human conscience of the traffic operators and managers of traffic infrastructure. The problem solution lies in defined legal and technical regulations in the area of railway traffic noise control.

It should be mentioned that railway noise management, from the aspect of railway infrastructure, is not conducted only in maintenance phase. It starts in the phase of planning and designing and continues in the construction and maintenance phases during entire service life. Since wheel rolling along the rails is the primary source of noise in the widest range of service speeds of vehicles on the conventional railway

network, a special attention must be paid to construction and maintenance of the tracks and vehicles.

Acknowledgement: This research was conducted at University of Niš, The Faculty of Civil Engineering and Architecture in the framework of the research program in the field of technological development in the period 2011-2014, in the domain of Transport, town planning and civil engineering, project TR 36016- Experimental and theoretical investigation of frames and plates with semi-rigid connections from the view of the second order theory and stability analysis and TR 36028-Development and improvement of methods for analyses of soil-structure interaction based on theoretical and experimental research, financially supported by the Ministry of Education, Science and Technological Develpment of the Republic of Serbia.

REFERENCES

[1] A. Buchman: *Feste Fahrbahn und Larm - Gibt es hier Lösungen?, Vortrag, Institut für Strassen- und Eisenbahnwesen*, Universitat Karlsruhe (TH), 2006, S.56.

[2] Z. Popović, L. Puzavac, L. Lazarević, „*Značaj železničke infrastrukture u upravljanju bukom"*, 2nd International Scientific meeting, GTZ 2012., Tuzla, pp. 1121-1128

[3] W. Schöch: Entwicklung von Schleifstrategien gegen Rollkontaktermüdung - Ein internationaler Überblick, ZEV rail Glasers Annalen 132, 2008, S. 2-10.

[4] Generalni projekat modernizacije železničke pruge: Beograd-Stara Pazova-Šid-Gr. Hrvatske, na životnu sredinu, Saobraćajni institutCIP, Beograd 2007.god.

[5] Prethodna analiza modernizacije železničke pruge: Beograd-Stara Pazova-Šid-Gr. Hrvatske, na životnu sredinu, Saobraćajni institutCIP, Beograd 2007.god.

[6] Z. Isaković: "*Uticaj modernizacije železničke pruge Beograd-Stara Pazova-Šid-Gr. Hrvatske, na životnu sredinu"*, VI naučno stručno savetovanje, Ocena stanja, održavanje I sanacija građevinskih objekata I naselja. SGIS, Divčibare 2009, str: 525-530.

[7] Zakon o zaštiti životne sredine (Sl. Glasnik RS, br.135/04)

[8] Zakon o proceni uticaja naživotnu sredinu (Sl. Glasnik RS, br.135/04)

[9] Z. Popović, L. Puzavac, L. Lazarević, „*Šinski sistemi i zaštita urbanog okruženja od buke, Ecologica"*, Volume 18(63), 2011, str. 434-438

[10] M. Hecht: Lärmbelastung durch Schienengüterverkehr, Vortrag, TU Berlm, 2003, S. 31



University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

ELEMENTS OF AIRCRAFT NOISE MANAGEMENT

Ljubiša Vasov, Slobodan Gvozdenović, Olja Čokorilo, Petar Mirosavljević, Branimir Stojiljković

University of Belgrade, Faculty of Transport and Traffic Engineering, Serbia, lj.vasov@sf.bg.ac.rs

Abstract - *Aircraft noise is one of the key environmental issues, with which in a specific way are faced practically all segments of air transportation system. Various efforts that are undertaken in solving of this problem are primarily aimed at limiting or reducing the number of people exposed to the impact of aircraft noise. A further increase of population exposed to aircraft noise can be expected when taking into account the anticipated growth in air traffic and the existing possibilities of operational improvements. This indicates the need to consider and harmonize various aircraft noise abatement measures and to achieve maximum effectiveness of their implementation in terms of environmental effects and costs, which is particularly emphasized in the recommendations of the ICAO balanced approach to aircraft noise management. The basic principles of a balanced approach to aircraft noise management are shown in this paper, with a closer review of a potential opportunities and limitations in the use of operational noise abatement procedures. Furthermore, special attention is directed to the economic instruments for noise abatement, such as the introduction of special noise charges at some airports. Based on the systematization of a different noise charge calculation methods, the comparison and the analysis of noise charges for a certain types of aircraft are performed.*

1. INTRODUCTION

After more than five decades, the problem of aircraft noise, which has been arising during the 60's of last century as a consequence of a jet engines introduction in civil aviation, is still one of the main topics of discussion on the environmental protection. During this period, a significant progress was made in dealing with noise generated by aircraft, both in the fields of aircraft construction and the development of operational procedures, as well as in the field of regulation.

Technological progress enabled the production of aircraft that are now 75% quieter than they were 50 years ago [1]. Also, various aviation organizations introduced a series of regulations and recommendations (Federal Aviation Administration - FAA Part 36, International Civil Aviation Organization - ICAO Annex 16, European Aviation Safety Agency - EASA CS-36), which were becoming more restrictive in regard to the allowable noise levels [2]. During the 70's of the last century, in less than one decade, the certification requirements for aircraft noise were moved from Chapter 2 to a much more stringent Chapter 3, which has been valid until 2006, when ICAO Chapter 4 certification requirements came into force.

It should be emphasized that the preparation and implementation of new and stringent requirements of the allowable noise levels, has been matched with the application of new technology and improvements in the aircraft and engine production (Figure 1). The increase of engine By-Pass Ratio – BPR has contributed significantly to the reduction of aircraft noise.

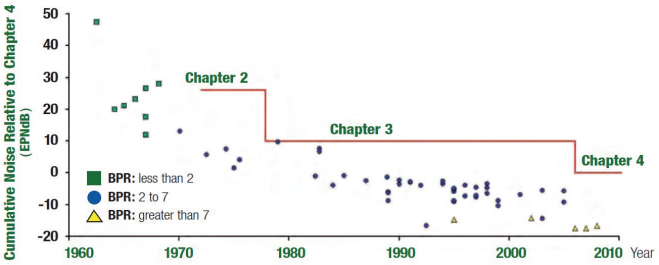


Fig. 1 *Aircraft Noise Standards Development*

In despite all of the activities, further deterioration in the field of aircraft noise pollution can be expected in the following decades, due to an intensive growth of air traffic. One of the ICAO's main goals in the environmental protection is to limit or reduce the number of people exposed to significant aircraft noise. The annual increase of population exposed to aircraft noise is expected to be between 0.7% and 1.6% when taking into account the anticipated annual growth in air traffic of 4.8%. According to ICAO's data [1], the number of people that will be exposed to aircraft noise over the next three decades is expected to raise from 21.2 million in 2006 to 26.6 or 34.1 million, depending on the implementation of different noise abatement technologies (Figure 2).

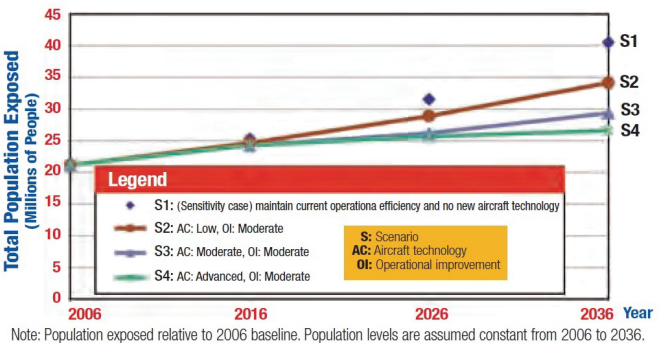


Fig. 2 *Population Exposed to Aircraft Noise Above 55DNL*

There are a number of activities in air transport, which are involved differently in the overall problem of aircraft noise.

Certainly, the noise in the vicinity of an airport is a major cause of adverse community reactions related to the aircraft operations (take-off, landing, engine testing, etc.), the airport expansion and the development of its infrastructure.

Many airports in Europe and USA have taken a number of various measures of aircraft noise abatement, which gave positive results. The emerging problem was directly related to the difficulty in preserving the achieved noise reduction results and matching them with the demands in the growth of air traffic. Thereby, the problem of aircraft noise has become one of the limiting factors for the development of air transport. Besides, the uncoordinated development of national and regional programs of aircraft noise abatement could hinder the role of civil aviation in economic development.

Bearing in mind the previous problems, in September 2001 ICAO established a global policy on aircraft noise named "*Balanced Approach to Aircraft Noise Management*" [3]. This concept emphasizes the necessity of considering different noise reduction measures at international airports, whose implementation must be coordinated with the rise of the noise at each individual airport, in order to achieve maximum environmental effects and maximum cost effectiveness of their implementation.

2. BALANCED APPROACH

The balanced approach to aircraft noise management includes a series of activities, aimed to identify airport noise problems and analyze the application of available noise abatement measures in a comprehensive and economically viable way. Thereby, it is necessary to take into account the characteristics of the considered airport for obtaining a solution that is appropriate to the local noise problems. This approach of noise management is based on a review of opportunities and the combination of four principal elements [3]: the reduction of noise at source, land-use planning and management, noise abatement operational procedures, and operating restrictions on aircraft.

2.1 Reduction Of Noise At Source

Reducing noise at source is related to the revision of noise standards, in order to reflect the current state and track the achieved benefits of the latest technology in aviation. This element of a balanced approach is not under the control of airports, and the adoption of certification standards is the responsibility of the Aviation Authorities and ICAO Contracting States, which apply the standards contained in Annex 16.

It should be emphasized that the reduction of noise at source is not limited only to the development of more stringent standards for the new and quieter types of aircraft. The reduction of noise at source can also be achieved through the continuous technological improvements of an aircraft during its life cycle, whose progressive integration into the fleet further contributes to improving the overall fleet noise performance. Thereby, for the assessment of an airport noise situation, it is necessary to take into account the following factors [3]: the integration of technological improvements in the fleet that meet the latest standards, the fleet renewal plans of an airlines that operate at the airport, the national plans for adoption of new noise standards, and the adoption the latest ICAO noise recommendations by Contracting States.

Besides being essentially dependent on the technology, the reduction of noise at source also depends on a number of other factors such as: economic and market conditions, fleet developments, growth of air traffic, air traffic management, airport infrastructure, economic instruments, etc. Taking into account a complexity of the mutual relations of the above factors and their combined effects, there is a high degree of uncertainty regarding to the prediction of noise reduction at source. It is therefore necessary to improve communication between the stakeholders (airports, manufacturers, operators, authorities, air traffic service providers, neighbor associations) for better understanding of the potential evolution of the noise situation at an airport.

2.2 Land-use planning and management

Considering the statement of ICAO Assembly that "*the number of people affected by aircraft noise is dependent on the way in which the use of land surrounding an airport is planned and managed*", the basic goal of land-use planning and management is to encourage compatible land use around the airport for the industrial and commercial purposes, and to steer the construction and the development of residential areas away from the airport area. Although land-use planning and management may not be directly related to the aeronautical problems, it is still one of the principal elements of the Balanced Approach.

It is important to timely identify effective land-use measures that can provide long-term benefits. In the case of already existing airport with limited possibilities of land-use changes, it is necessary to prevent additional incompatible land use in areas, in which due to the reduction of noise at the source, a lower noise levels with a closer noise contours to the airport boundary has been achieved.

The minimization of noise problem can be achieved through preventive measures, such as [3]: selecting location for a new airport away from noise-sensitive area, consideration of all available measures of land-use management during the initial stage of new airport planning or existing airport development, proper noise zoning around the airport area by taking into consideration the noise levels, population density, air traffic growth, etc. There are three categories of land-use planning and management measures:

- planning instruments (comprehensive planning, noise zoning, subdivision regulation, etc.),
- mitigating instruments (building codes, noise insulation and barriers, land acquisition and relocation, etc.), and
- financial instruments (capital improvements planning, economic incentives, noise-related airport charges).

The responsibility for land-use planning and implementation of the control measures mostly belongs to the local or regional authorities, but the airport authority should certainly work closely with the competent local authorities, that can take some of the measures too. For example, the national or local governments may impose noise-related airport charges, but also the airport authority may introduce noise related charges as additional landing and take-off fees. Currently, there are a number of models for the calculation of noise charges, which are quite different between airports.

2.3 Noise abatement operational procedures

The size and the shape of noise contours depend on many factors, such as operational factors (aircraft weight and engine power settings, flight path), atmospheric conditions in connection to sound propagation (wind, temperature, relative humidity) and surface condition shielding. The application of noise abatement operational procedures that affect the size and the shape of noise contours, as part of the balanced approach, include a number of different operating procedures that could be implemented in flight or on the ground. Three types of possible actions can be distinguished: using runways, whose initial and final flight paths are far from the noise-sensitive areas, using departure and arrival routes in order to avoid noise-sensitive areas under or close to usual flight paths and using noise abatement take-off or approach procedures.

The introduction of noise abatement operational procedures should be carried out when the noise problem at the airport really exists, while complying with all of the requirements of flight safety, which always has the highest priority in aviation. The results that are achieved using some of the noise abatement operational procedures depend on the aircraft type, as well as on the operators, who often restrict pilot operations to the maximum of two procedures for the reasons of flight safety. In addition, the application of noise abatement operational procedures is limited only to those aircraft whose actual performances can meet the requirements of the particular procedure.

It should be noted that in some cases the implementation of noise abatement operational procedures could lead to the creation of new problems that may result with the exceedance of noise levels in some areas around the airport, due to changes in the size and the shape of noise contours. Attention should be paid to the selection of appropriate procedures, so that their application would not compromise or undermine the achievements of noise abatement. There are a number of noise abatement operational procedures, which can be divided into six groups [3]:

- use of flight departure and approach routings (noise preferential routes, sid/star procedures, dispersed flight tracks, automated arrival and departure procedures),
- use of runways (noise preferential runways, displaced thresholds),
- use of departure procedures (noise abatement departure procedures),
- use of approach procedures (descent profiles, reduced power/reduced drag techniques, Continuous Descent Approach – CDA),
- use of reverse thrust, and
- use of ground-based operational procedures.

The most promising noise abatement short-term and medium-term procedure is the application of continuous descent approach, which can even provide an emission benefits.

2.4 Operating restrictions on aircraft

According to Balanced Approach [3], an operating restriction is defined as "*any noise-related action that limits or reduces an aircraft's access to an airport*". There are several examples of operating restrictions, as: defining the maximum number of operations at an airport, defining noise quotas for limiting total noise level around the airport, night-time restrictions, limiting or prohibiting operation of the noisiest aircraft, etc. Four categories of operating restrictions can be distinguished: global, aircraft-specific, partial and progressive. They can be implemented through decreasing the number of operations at an airport and introduction of quotas that reflect the combined effect of the number of aircraft operations and aircraft acoustic characteristics.

These restrictions enable restraining or shrinking the noise contours around the airport, but they should be only one part of all of the implemented measures for noise abatement. In this regard, ICAO recommends the introduction of operating restrictions only after considering the effects of the application of other elements of the Balanced Approach. It should be noted that the long-term results in reducing the noise at the airport, can be achieved using a combination of concurrent and multiple elements of the Balanced Approach. Thus, the reduction of noise at the source by applying the operational procedures (such as CDA) and the operational restrictions, can bring good results in the first step, which can be preserved for a longer period with the implementation of land-use planning and management.

3. CONTINUOUS DESCENT APPROACH

Different descent and approach techniques, especially Continuous Descent Approach – CDA, are attracting a lot of attention today, as the most promising flight procedures for noise abatement. The basic idea of CDA is to keep an aircraft at higher altitudes and at lower thrust levels over a longer period of the approach, as compared to the conventional (step-down) approach (Figure 3).

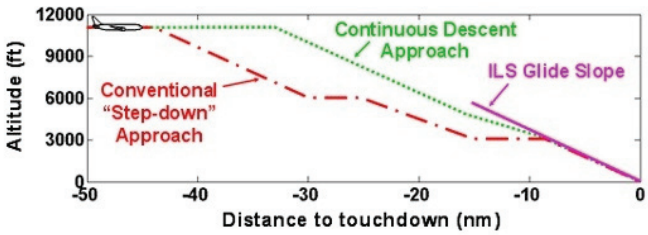


Fig. 3 *CDA and Conventional "Step-down" approach*

The conventional approach procedure typically involves the periods of a flight with a constant altitude and speed. The combinations of a lower flight levels in the conventional descent and approach, with frequent increases in thrust, is leading to significant noise exposure levels. In contrast, the CDA does not contain segments of level flight at low altitudes and thus eliminates the need to create thrust necessary to maintain level flight. This allows the aircraft to fly at higher altitudes with lower thrust before the intersection of ILS signal (Instrument Landing System – ILS), thus reducing the noise exposure levels. Basically there are two types of CDA approaches: Basic CDA and RNAV CDA (Area Navigation – RNAV).

In basic CDA, air traffic controller estimates the distance of an aircraft from the runway and announces it to the pilot of an airplane along with a vector. Flight crew uses this distance to determine the appropriate rate of descent in order to perform CDA procedure. However, considering that the distance to the runway estimated by air traffic controller is

uncertain, two situations can occur: if the estimated distance is less than the actual, the airplane has to move to a level flight and if the estimated distance is greater than the actual, the airplane has to increase it's rate of descent, what can lead to a missed approach.

Such problems can be eliminated by using RNAV CDA procedure, which implies the existence of a predefined aircraft's path in the form of a series of waypoints, with the required altitude and speed on each of them. Considering that the aircraft's distance from the runway is accurately determined, the rate of descent can be optimized during the development of the procedure, which completely eliminates the need for the level flight and achieves the highest level of noise reduction. Such a path can be programmed into the aircraft navigation equipment such as Flight Management System – FMS, and airplanes that use this procedure fly in a narrow band, which is very good in terms of noise reduction. In addition, RNAV CDA procedure can be designed so that it can be used for different types of aircraft (different performances) and environmental conditions (wind).

Past experiences have shown that the application of CDA procedures, in comparison to the conventional approach, could reduce the noise level about 5 dB, depending on the aircraft type. For example, the experimental research conducted on flight simulators for the A320-231 aircraft, showed that CDA profiles as compared to the conventional approach provide a significant reduction in noise level from 2 to 9 dB at 45 to 20 miles from the threshold. This noise reduction is mainly due to the higher profile and less speed. However, it has been shown that there is an increase of local noise by about 4 dB at 17 km from the threshold due to the earlier extraction of slats. This deficiency can be minimized if the change of an aircraft's configuration during the approach can be delayed as much as possible. The reduction of noise contour size is 10-40%, but only over the flyover areas where CDA is applied. There are other restrictions on noise benefits when it comes to the CDA:

- CDA noise benefits are limited to locations typically around 10 to 25 miles from the runway,
- from interception point of the CDA path with the 3° glide slope to the runway, there is no difference between the CDA and the conventional approach,
- CDA has little effect on the noise contours near the airport, because the CDA noise benefits are concentrated relatively far away from the airport.

There are a number of limitations in the application of the CDA, which relate to various operational factors, such as:

- airport and airspace capacity constraints,
- airport/ground equipment,
- appropriate aircraft equipment,
- operational and Air Traffic Control – ATC constraints,
- aircraft and engine characteristics,
- flight crew and air traffic controller workload,
- weather conditions,
- regulations and safety requirements,
- airport configuration, terrain features and the presence of obstacles.

Today, the use of CDA procedures at Heathrow Airport in London and Schiphol Airport in Amsterdam is a common practice for eight years, especially during night operations. In addition to CDA noise benefits, due to the reduced thrust requirements in the final phase of the flight arrival, a significant fuel savings from 20 to 40% in the final 35 to 45km of flight can be achieved [4].

4. NOISE CHARGES

As one of the economic instruments of the land-use planning and management in the balanced approach to aircraft noise management, some airports impose the noise-related charges for aircraft that exceed the allowable noise levels or for older noisier types of aircraft. Airports in Europe and all around the world are constantly joining to this practice, so airlines are forced to pay the additional fee for the excessive noise or to consider the modernization of their fleet with low-noise aircraft. Also, noise-related charges should be imposed in order to finance different noise-mitigation measures.

According to the EU Directive on the calculation of noise charges [5], "*noise charge means a specific noise levy by the airport, related to the certificated noise characteristics of the aircraft, which is designed to recover the costs of alleviation or prevention of noise problems and to encourage the use of less noisy aircraft*". The difference should be made between two terms: noise-related landing and take-off charges that provide the opportunity to instigate use of less noisy aircraft, and specific noise charges that are imposed in connection of measures for the alleviation or prevention of noise problems.

There are various models for the calculation of the noise charges, whose calculated amounts may vary depending on the: weight of an aircraft, take-off and landing schedules over a twenty-four hour period, aircraft noise characteristics, etc. Some of the models are very simple and based only on the Maximum Take-Off Weight – MTOW (Iran) or the number of passengers (Dominica), but others are more complex, which include a number of noise related factors. By the systematization of different noise charge evaluation and calculation methods [6], two general principles can be recognized:

- the evaluation of noise charges in accordance with the accepted aircraft classification into several categories according to their noise characteristics (usually based on the data of aircraft noise certificate established according to ICAO provisions), and
- the calculation of noise charges, according to the appropriated formulas (usually based on the certificated aircraft noise levels at arrival and departure).

Many of these calculation methods include additional noise related factors: day/night operation, type of the movement, etc. Due to different approaches in the calculation of noise charges, the obtained results for the same type of aircraft at different airports, were noise related charge is levied, can differ significantly. In an example, a few European airports with different methods of noise charge calculation are considered for three types of aircraft (Boeing B737-300, Airbus A320-211 and A318-111). Based on the information provided in the ICAO Doc 7100 [6], a brief description of the noise calculation methods is presented for the following European countries: Finland, Hungary and Netherlands.

1) Finland (Helsinki – Vantaa airport)

The noise charge is calculated using the following formula:

$$\text{Charge} = C_d \cdot 10^{\frac{L_d - T_d}{10}}, \quad (1)$$

where: C_d is unit rate (C_d = 6.93 EUR), L_d is mean of the sideline and take-off noise levels of the individual aircraft in accordance to ICAO Annex 16, and T_d is minimum threshold at departure equaling (T_d = 86 EPNdB).

This noise charge is imposed only for turbojet aircraft and for departures between 23:00 and 06:00.

2) Hungary (Budapest – Ferihegy airport)

The noise charge is calculated with the following formula:

$$\text{Charge} = A \cdot K \cdot N \cdot M, \quad (2)$$

where: A is unit rate (A = 7.00 EUR/movment), K is aircraft category factor, N is time of the day factor and M is type of the movement.

Airplanes are divided into four noise categories:

I category (K = 0.4),

II category (K=1.0),

III category (K=1.8), and

IV category (K=3.0).

Day is divided into 4 intervals, and time of the day factor is:

- Daytime (06:00-22:00): N = 1.0,
- Evening (22:00-24:00): N = 1.5,
- Night (24:00-05:00): N = 10.0, and
- Morning (05:00-06:00): N = 1.5.

Also, aircraft operations are distinguished by the type of the movement: for take-off M = 0.91 and for landing M = 1.1.

3) Netherlands (Amsterdam – Schiphol airport)

Noise surcharge as an additional part of the basic landing and take-off charges is determined by aircraft noise categories:

- noise category MCC3: $0 \geq \Delta\text{EPNdB} > -5$,
- noise category A: $-5 \geq \Delta\text{EPNdB} > -9$,
- noise category B: $-9 \geq \Delta\text{EPNdB} > -18$, and
- noise category C: $\geq \text{EPNdB} \leq -18$,

where ΔEPNdB is the difference between the sum of the three EPNdB noise certification values for an aircraft, and the sum of the three Chapter 3 limit values (in accordance with ICAO document Annex 16, Volume 1).

According to the previous aircraft noise categories, for each landing and take-off charge, there are surcharges or discounts over and above the basic compensation [7]:

- noise Category MCC: base charge increased by 60%,
- noise Category A: base charge increased by 40%,
- noise Category B: base charge, and
- noise Category C: base charge reduced by 20%.

Basic charge is dependent on the: MTOW, aircraft category (A, B, C, MCC3), point of time (day/night) and type of aircraft operation (landing/take-off).

In order to compare the presented methods for the calculation of noise charges, only the take-off operations during the night are considered here. The additional data on the aircraft noise levels for jet airplanes are taken from the EASA TCDSN (Type-Certificate Data Sheet for Noise – TCDSN) database (Issue 14) and the obtained results of noise charges calculation are shown in Table 1.

Table 1 *Noise charges evaluation (EUR)*

	B737-300	A320-211	A318-111
Finland Helsinki - Vantaa	9.1	12.5	9.2
Hungary Budapest - Ferihegy	63.7	63.7	63.7
Netherlands Amsterdam - Schiphol	258.4	0.0	-79.3

Obviously, there are significant differences between the noise charges for the same type of aircraft, on the considered airports. This is the result of applying completely different methods for the noise charge calculation and the classification of aircraft noise categories.

For example, for the considered types of aircraft at the Budapest Ferihegy airport, the same amount of noise charge is levied, because their classification puts these aircraft into the same noise category - II category (K=1.0). As contrary to the previous, there is a significant difference of the noise surcharges between the considered aircraft at the Schiphol airport, because by their classification the B737-300 (Chapter 3 aircraft) belongs to the A noise category, A320-211 (Chapter 4 aircraft) to the B noise category, and A318-111 (also Chapter 4 aircraft) to the C noise category. It should be mentioned that for the A318-111, which is considered as relatively low-noise aircraft, there is a discount on the basic compensation of 79.3 EUR.

The Vantaa airport model for the noise charges calculation gives results that are more balanced. This model is derived from the Amended proposal to EU Directive on the calculation of noise charges [5], where the total noise charge for one arrival and one departure at a given airport is:

$$C = C_a \cdot 10^{\frac{L_a - T_a}{10}} + C_d \cdot 10^{\frac{L_d - T_d}{10}}, \quad (3)$$

where: C_a and C_d are the unit noise charges at departures and arrivals for the considered airport, L_a is the certificated noise level at approach, L_d is mean of the certificated noise levels at the flyover and lateral measurement points, and T_a and T_d are noise thresholds at departures and at arrivals corresponding to the categories of relatively quiet aircraft for the considered airport.

With the small modification, the same model (equation 3) was applied only in Sweden, where the noise charge is applied to the aircraft with MTOW that exceed 9 tones, and calculated according to the next formula:

$$C_{tot} = C \cdot \left(10^{\frac{L_a - T_a}{10}} + 10^{\frac{L_d - T_d}{10}} \right), \quad (4)$$

where: C_{tot} is charge for one landing and C unit noise charge.

The main difference between the previous two models is in the fact that in the Sweden model, the unit noise charges are not being separated for arrivals and departures.

In that respect, the proposed model (equation 3) for the noise charge calculation gives the possibility of applying the same calculation rules, with the permissible variation of the unit noise charges. For example, the usage of different unit charges for departures and arrivals at different times of the day can reflect the relative importance of the actual noise emissions for the impacted neighbors' population at the considered airport.

5. CONCLUSION

The ICAO's goal of sustainable growth is directly related to the noise, emphasizing the importance of the balanced approach to aircraft noise management. The aim of the balanced approach policies is to obtain maximum environmental benefits in the most cost-effective manner. The achievement of this goal implies the integration of four elements in the balanced approach: the reduction of noise at source, land-use planning and management, noise abatement operational procedures and operating restrictions on aircraft. A combination of these elements is needed not only for improving the noise situation around an airport, but also for preserving the potential long-term benefits.

One of the noise abatement procedures that attract an attention is the CDA procedure. The environmental facts clearly highlight the advantages of the CDA procedures in relation to the conventional "step-down" approach. In order to improve the CDA, there is a development of the more promising Advanced Continuous Descent Approach – ACDA as a concept which is oriented to complying with the Air Traffic Management – ATM system.

The levying of noise charges, as a financial instrument, should provide the inducement to reduce noise impact and funds to recover the costs applied to noise abatement and prevention. A well-balanced and proper policy for noise related charges is leading airlines to consider aircraft noise when making their management decisions. According to the ICAO policies [3], the introduction of noise related charges should be based on the several principles, such as: "*noise charges should be levied only at the airports experiencing noise problems, should be non-discriminatory between users, should be designed to recover no more than the costs applied to their alleviation or prevention*", etc.

Another aspect of the problem of noise charges is matching of the methods for their calculation. The models for noise charge calculation should be based on the actual aircraft noise impact, taking into account all relevant elements, such as the usage of noise abatement flight procedures.

Because of the anticipated growth in air traffic, it is certain that the noise problem will not lose its actuality in the coming decades. Today, a great importance is given for every issue of the aircraft noise problem and a number of professional organizations are dealing with this. Therefore, a further improvement and development of new measures for aircraft noise abatement can surely be expected. In addition, it is necessary to establish the conditions for sustainable development of air transport, concerning the balance between safety, economy and enviromental protection.

REFERENCES

[1] *Environmental Report*, ICAO, 2010.

[2] Ljubiša Vasov, "Tendencies in the Approach of Air Traffic Noise Problem Solving", *XIX Yugoslav Conference with International Participation – Noise and Vibration*, Niš, 14-15 October, 2004.

[3] *Guidance on the Balanced Approach to Aircraft Noise Management,* ICAO Doc 9829, AN/451, Second Edition, 2008.

[4] Petar Mirosavljević, Slobodan Gvozdenović, Olja Čokorilo, "Continuous vs. conventional descent of transport aircraft", *in Proceedings of 12th International Conference Dependability and Quality Management ICDQM-2009*, 25-26 June 2009, Belgrade, pp. 293-304.

[5] European Parliament, *Directive of the European Parliament and of the Council on the establishment of a Community framework for noise classification of civil subsonic aircraft for the purposes of calculating noise charges*, Amended Proposal COM(2002) 683 final, Brussels, 29.11.2002.

[6] *Tariffs For Airports And Air Navigation Services*, ICAO Doc 7100, 2010 Edition.

[7] Amsterdam Airport Schiphol, *Schiphol Airport Charges and Conditions*, Adjusted 1 April 2012.

University of Nis
Faculty of Occupational Safety

„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

ANALYSIS OF NOISE LEVEL GENERATED BY HELICOPTERS WITH VARIOUS NUMBERS OF BLADES IN THE MAIN ROTOR

Bojan Tatić, Nebojša Bogojević, Slobodan Todosijević, Zlatan Šoškić

University of Kragujevac, Faculty of Mechanical Engineering Kraljevo, Serbia; tatic.b@mfkv.kg.ac.rs

Abstract -*The possibility of landing and take-off from a small space and overflights at low altitudes makes horizontal propeller aircrafts (helicopters) significant sources of internal and external noise in the environment. Given the typical aircraft structure in relation to other aircraft, local sources of noise in helicopters are numerous: the main rotor, tail rotor, the propulsion system, transmission and others. Particular impact on the overall level of noise that is generated has the number of blades in the main rotor of a helicopter. This paper presents the results of measurements of noise generated by helicopter SA341H "Gazelle" at full throttle in the work on the land and take-off phase. The level of noise generated by helicopter type SA341H "Gazelle" was compared to the levels of noise generated by the helicopters Robinson R44 Clipper and Bell 206B.*

1. INTRODUCTION

One aspect of the project "urbaNoise" is a study of the noise impact of traffic on the urban environment. Sources of noise in urban traffic noise are road traffic, railway traffic noise, and aircraft noise. Influence of aviation noise on the population of the urban areas has different effects compared to the noise of the road transport.

As the term aviation noise, or aircraft noise, we consider "unpleasant" sound that comes from the aircrafts when they overfly populated places during various phases of flight. Aircrafts are bodies that are separated from the ground, and according to the way they move, they are divided into aerostats, which have the ability to hover, and aerodynes, which have the ability of progressive motion. From the standpoint of aircraft noise emission, they are divided to aircrafts with motor drive (airplanes, helicopters, gyrocopter, gyroplane, hang gliding, motor gliders, rockets ...) and the non-engine-powered aircrafts (gliders, kites, balloons, parachutes, paragliders ...).

2. CHARACTERISTICS OF AIRCRAFT NOISE

Aircraft noise is characterized by high levels of noise that arise during short periods. Its characteristics depend on the source of noise, ie. type of the aircraft that emitts the noise. In this regard, it is important to emphasize that aircraft noise arises as the result of movement of the aircraft through the air (aerodynamic noise) and because of work of the propulsion system - engine.

Aerodynamic noise occurs as a consequence of the specific flow (turbulence) around the aircraft structure, cavities, control holes and surfaces and landing gear of an aircraft.

The noise that is a result of the propulsion system is determined by the type of aircraft engines, which may be:

- internal combustion engines - piston engines and Wankel engines,
- reactive engines - jet engines, compressor reactive engines and rocket engines,
- without combustion engines - human powered and electric motors.

The piston engines have broadest application, in light motorized aircraft and jet engines in passenger, cargo and fighter aircrafta. Piston engines are used for subsonic flight speeds, while jet engines drives for supersonic aircrafts.

Influence of the aircraft noise on residents of urban areas depends on the distance of the area from the runway (airports, heliports, airports sports). Near the airport, the population is not exposed only to the impact of the aircraft noise, but also to the noise generated at the airport by the necessary devices and equipment for safe takeoff and landing of aircrafts, mobile and fixed resources for servicing the aircrafts, anti-fire, medical and other occupant protection, warked and the flight crew, etc... These sources of noise have rather constant level during time, regardless of time of day, weather conditions and air traffic density. The biggest noise influence still have the aircrafts, especially during the phases of landing, take-off and taxiing (movement along the taxiway), when the primary noise comes from the propulsion system.

Each airport has a precisely defined procedure for take off and landing on a runway, which consists in the determination of velocities, altitudes, and bank angles. Air traffic control has defined the procedures for each airport based on its category. Categorization of airports was based on the size of the runway, which determines the size of the aircrafts, i.e. number and type of the propulsion system, which directly affects the level of aircraft noise.

Specificity of the helipads is that they are regularly placed in densely populated urban areas, often on the roofs of residential, commercial and hospital facilities.

3. CHARACTERISTICS OF AIRCRAFT NOISE WITH HORIZONTAL PROPELLER

Aircrafts with a horizontal propeller (helicopters) are aircrafts characterized by takeoff and landing from limited area. This does not mean that helicopters only take-off vertically, by raising hull and hovering in progressive flight: they are able to, and depending on the load, and they have to be able to

take-off from taxiing (aviation slang words – landing run-off). Of course, this refers to helicopters that have wheels as part of the landing gear.

From the standpoint of noise, what separates helicopters from the aircraft is the specificity of propulsion system, the existence of horizontally mounted rotor, the existence of tail rotor and the existence of the transmission system.

Propulsion systems that are installed on the helicopters are gas turbine engines and, rarely, piston and jet engines. Gas turbine engine is structurally very similar to the propeller-turbine engine. For propeller-turbine engine, a lift is created by the vertical propeller that is directly related to the turbine shaft (propeller engines on many passenger and cargo aircrafts). Gas-turbine engine transmits its power to the shaft, and then through the transmission system reduces the required horizontal rotor speed. In both of these types of engines the emphasis is on the transmission moment, and not at the speed of exhaust gases - thrust. In the construction, it is achieved by a small number of degrees of air compressor, and by large number of degrees of turbine engines.

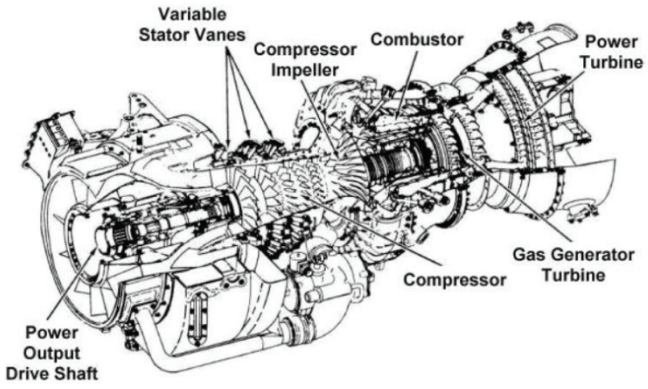


Fig.1 *Turboshaft engine [4]*

The advantages of this the propulsion systems are: high power, long life, small size and weight, easy maintenance, low complexity of construction, low vibration, while the main disadvantages are higher fuel consumption and higher prices of the development because of the specific materials for fabrication. Helicopters may have one or two engines and/or a start-engine.

The helicopter has six degrees of freedom, and five of them are regulated by main rotor, i.e. horizontally mounted propeller. The main rotor is made of a number of blades and the supporting head. The system is installed on the main gear that drives the motor shaft. Number of main rotor blades is in range from two to seven, and usually it is two, three or five. The construction of a blade is very similar to that of an airplane wing, only with a smaller surface area.

Steering of the sixth degree of freedom, rotation around a vertical axis, is achieved by rotating the tail rotor blades. It is important to emphasize that this is not the only solution. There are helicopters without tail rotors, but with two main rotors that turn in the opposite direction.

Transmission moment from the engine is transferred to the main rotor and tail rotor through the system transmission and shaft. The system consists of a toothed power transmission and rpm regulator.

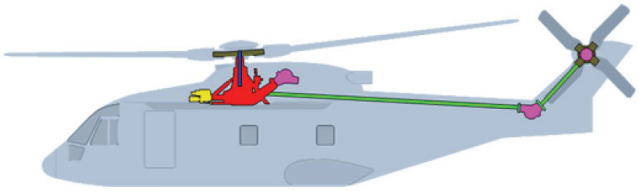


Fig.2 *Helicopter transmission [4]*

As it can be seen from the presented structural analysis of the helicopter, the helicopter noise sources are:

- propulsion system - engines,
- the main rotor,
- tail rotor (if applicable),
- transmission,
- air flow around the aircraft.



Fig.3 *Helicopter noise sources [5]*

4. OBJECT OF MEASUREMENT

Object of measurement noise is the helicopter SA341H French company "Aérospetiale" which was produced under license in the airplane factory "SOKO" in Mostar. It is a light multipurpose helicopter for use in civil and military aviation. The test helicopter is attack helicopter used for anti-armor rockets and firing low-speed targets in the air within of the Air Force of the Serbian Army.



Fig.4 *Helicopter SA341H "Gazelle-gamma" AFAS*

The helicopter has engine of type Astazou IIIB produced at the plant "May 21st" in Rakovica. It is a gas-turbine jet engine with fixed engine turbine, composed of the stator and rotor parts of axial and centrifugal compressors and turbines three-steps.

The aim of the study was to compare the level of noise emitted by the helicopter to the noise emitted by engines of similar power, design, and performance, but with a different number of main rotor blades, which are used in aviation in the Republic of Serbia.

Some characteristics of the engine, which can affect the production of noise, are:

RPM of tail rotor .....5774 rev / min

RPM of starter generator .....7808 rev / min

RPM of alternator.....11 968 rev / min

Flow within compressor ..... 2.6 kg / s

From the comparative table, it can be seen that the helicopter SA341H has similar characteristics as the helicopters B-206B and Robinson R44 Clipper.

Table 1 *Technical characteristic of helicopters*

	SA 341H	B-206B	R44
Length [m]	9.53	12.11	9.00
Width [m]	2.04	2.33	1.28
Height [m]	2.20	2.83	3.30
Kerb weight [kg]	850	777	658
Diameter MR [m]	10.50	10.16	10.06
No. blades MR [which]	3	2	2
Rpm MR [rev/min]	378	395	
Diameter TR [m]	0.69	1.65	1.50
No. blades TR [which]	13	2	2
Engine	Astazou IIIB	Rolls-Royce 250-c20J	Lycoming Io-540-AE1A5
Type of engine	gas turbine	gas turbine	piston
Type turbine engine	fiksna	slobodna	/
Engine power [kW]	440	313	183
Rpm engine [rev/min]	43500	53519	2718

From the standpoint of the analysis of noise generated by the helicopter as a source it is important to note that there are some structural differences between the two types of helicopters. Engine types are different, but with similar forces. However, Astazou engine has two modes - with relant and full throttle. Rolls-Royce Motors and Lycoming have a third mode called full correction, which corresponds to Astazou mode with full throttle. Full throttle mode in the two engines corresponds to rotor rpm when the engine load is approximately 93%.

In the transmission system of the helicopter SA341H there is centrifugal clutch, which is not the case with the other two helicopters. The result of such a design solution is that during engine work inn a relant mode of SA341H there is no turning of the rotor, which is not the case the other two helicopters.

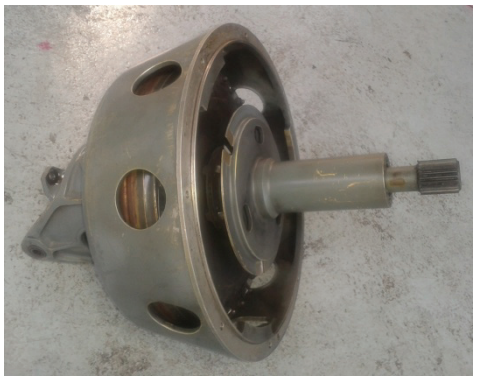


Fig. 5 *The appearance of the centrifugal clutch SA341H*

The tail rotor on the helicopter SA341H belongs to turbine type, i.e. it is built into the wing structure of vertical tail stabilizer, while the other two helicopters have free style tail rotor. For that reason SA341H helicopter has a smaller diameter of the tail rotor and has more blades, even though the function is the same.

It is also important to note that the helicopter is fully functional from technical and flying stadpoints, which was confirmed by examining the service documentation of the helicopters. The functional correctness comprises also resource status of each part of helicopters, engines and equipment.

5. METHODOLOGY

The measurement was performed at the central helicopter landing field on Ladjevci airport near Kraljevo. The helicopter was placed on a concrete base with no slope and oriented in the East-West directon. The closest barriers were located at a distance larger than 150 m. Weather conditions were established by instrument Testo 410-2, and the parameters of the time were clear sky, ambient temperature of 28°C, humidity of 31%, and the wind velocity of 3 m/s from East-Southeast.

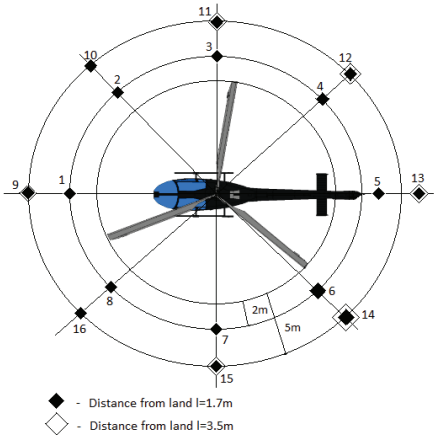


Fig.6 *Measuring points around the helicopter*

Sixteen measurement positions were selected, as it is shown in Figure 6. Th points were uniformly distributed with angular spacing of 45° relative to the helicopter centerline, starting from the axis of the helicopter in front of the cabine. They had distances 2 m and 5 m from the extreme edge of blade of the main rotor and vertical tail stabilizer in the direction of the helicopter centerline. At a distance of 2 m, measurements were carried out at a height of 1.7 m, and at a distance of 5 m, measurements were conducted at two heights: 1.7 m and 3.5 m. The duration of the measurement was 60 seconds, except for height of 3.5 m, where the measurement time was 30 seconds.

The measurement was made in pauses between the flights, and measurements of noise of during the take off phase were not performed.

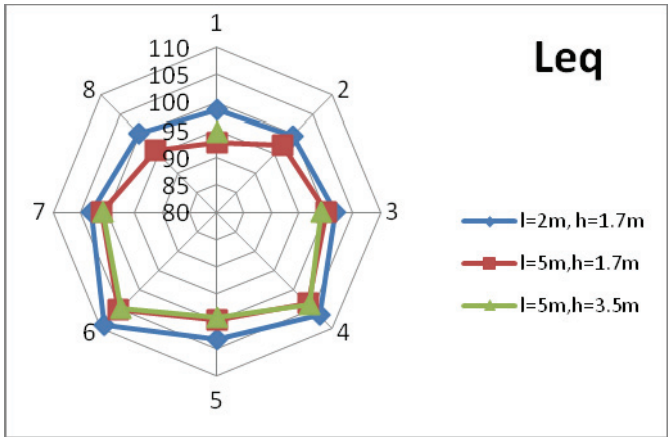


Fig. 7 *The equivalent noise levels at the measurement points*

Measurement equipment consisted of:

- Microphone unit Brüel & Kjær type 4188-A-021
- Acquisition card Brüel & Kjær Type 3560-B-120
- Notebook Acer Aspire 5732Z,
- Software Brüel & Kjær type Data Recorder.

6. RESULTS AND DISSCUSION

For data processing was used the software package Matlab. The analysis was performed in two ways:

- Analysis of time variation,
- Frequency analysis.

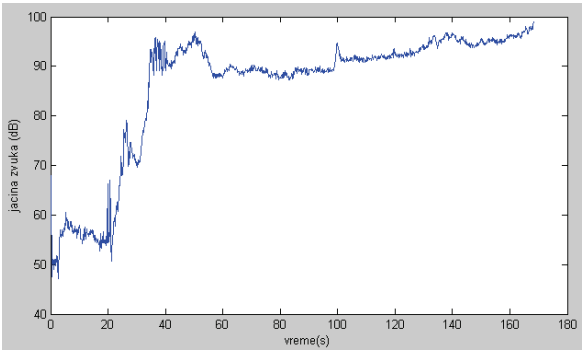


Fig. 8 *The level of noise taken at measuring point 3 during start of engine and rotor*

When the analysis of time variation was performed, averaging was done every 0.125 s, with a sampling frequency of 8192 Hz. This choice was made because the research is primarily intended for the purposes of protection from urban noise, and the rules of construction acoustics were applied. It is shown that in this way the noise spectrum covered spectra of all important noise sources on the investigated helicopter.

The measurement results are presented by a spatial equivalent noise level diagram shown in Figure 7.

The results of measurements during engine start from zero to full throttle are shown in Figures 8 and 9:

Because of the variety of design and operating principles of engines and rotors at relant, it is not possible to compare the noise levels emitted SA341H helicopter helicopters with B-206B and R44 in that regime.

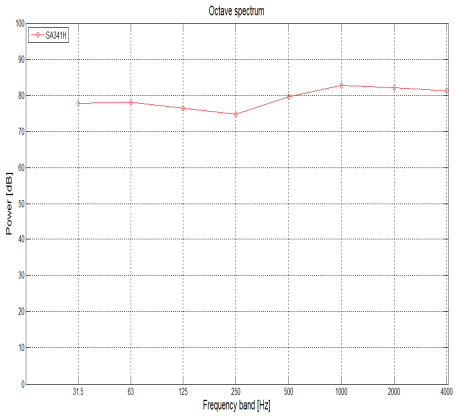


Fig. 9 *Octave-band analysis of noise measurements taken at measuring point 3 during engine and rotor start*

SA341H helicopter noise level at full throttle, measured from a distance of 2 m from the edge of the blade of the main rotor taken at measuring point 6, is comparable to the noise levels of helicopters B-206B and R44 at full correction, as shown in Figure 10 [3]:

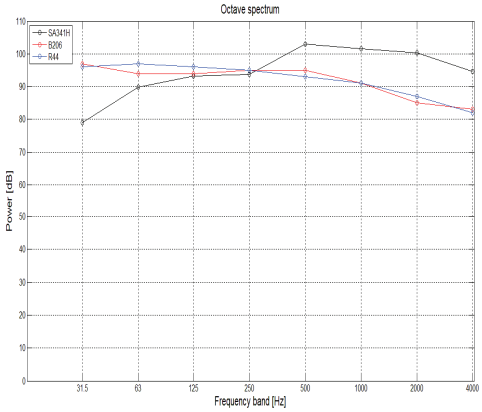


Fig.10 *Octave-band noise in full throttle for helicopters SA341H, B-206B and R44*

The noises levels emitted by helicopters B-206B and R44, shown in Figure 10, were obtained by measuring at the distance of 3 m from the edge of blade of the main rotor [3]. Figure 9 shows octave-band noise during starting of the engine and rotor, taken at measurment point 3. High frequency noise is emitted by the compressor and turbine rotary engine parts, and the low frequencies noise is consequence of rotation of the main and tail rotors.

From the Figures 8 and 9 the following may be concluded:

- During the period 0-22 s variations of the level of noise are caused by operation of the engine ingnition and combustion of the mixture in the combustion chamber during ingnition;
- During the period from 22-45 s starts turning of the motor shaft and turning of compressor and turbine startup engine parts, causing a sudden jump of the noise level;
- During the period 45-48 s the engine is running at relant;
- During the period 48-57 s arises hitching i.e. transmission of torque from the engine to the main rotor through the centrifugal clutch,

- During the period 60-170 s engine and rotor comes to the full throttle regime.

From the Figure 10 it can be concluded that the high noise levels (over 100 dB) occur arund the frequency of 40 Hz and in the frequency range of 400-2000 Hz, which indicates that the rotor and the engine produce similar levels of the noise. This spectrum is characteristic for the measurement points exposed to the higher influence of engine noise, because the exhaust pipe is slightly angled to the left, relative to the helicopter centre line, looking in the direction of the helicopter flight.

7. CONCLUSIONS

The measurements of noise levels of helicopter SA341H by the selected methodology showed that the noise levels at the measuring points have similar values for both distances from the edge of the main rotor blade, and that they can be compared to the values shown in Figure 10, which were measured at distance of 3 m. This paper used the noise levels at a distance of 2 m from the edge of blade of the main rotor.

By performing an analysis of the octave-band noise with SA341H, B-206B and R44 helicopters, the following conclusions can be drawn:

- Helicopter SA341H creates a higher level of noise at the frequencies close to 40 Hz, which corresponds to noise from the main rotor, but at other frequencies in the frequency range of 31.5-125 Hz, that also show the influence of main rotor noise levels, the helicopter SA341H has lower noise levels than the helicopters B-206B and R44.
- Helicopter SA341H has approximately the same level of noise as helicopters B-206B and R44 in the frequency range of 150-300 Hz, which corresponds to the impact of the tail rotor;
- Helicopter SA341H has higher noise levels than helicopters B-206B and R44 in the frequency range of 400-2000 Hz, corresponding to the impact of the engine.

In order to determine more reliable values of noise levels emitted by the main rotor, it is necessary to peform measurements with fixed flight controls, to reduce the impact of a sense of the pilot to maintain of the main rotor rotation in one plane. However, it can be concluded that helicopter with three blades in the main rotor emits less noise in low frequency range than helicopters with two blades in the main rotor. Higher noise levels in the high frequency spectrum of of the helicopter SA341H, compared to B-206B and R44, is expected because of the the engine that the helicopter SA341H uses.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to Serbian Ministry of Education and Science for support through project TR37020.

REFERENCES

[1] M. Praščević, D. Cvetković, " Environmental Noise ", University of Nis-Faculty of Occupational Safety, (2005)

[2] J.Bera et al, “Investigation of the helicopter noise”, *ICAS 2000 Congress*, (2000)

[3] D. Novak, T. Bucak and D. Miljković, “Comparative helicopter noise analysis in static an in-flight conditions”, *Acoustics ’08 Paris*, pp.4061-4064 (2008)

[4] Željko Božić, “Basis of the construction of helicopters, "University of Zagreb-Faculty of Mechanical Engineering - Study of aviation, the script,(2010)

[5] E. Greenwood, F. H. Schmitz,” A Parameter Identification Method for Helicopter Noise Source Identification and Physics-Based Semi-Empirical Modeling”, *NASA Langley Research Center*, (2008)

[6] EASA, “Type sertificate data sheet No.IM.R.512”, *Type sertificate holder Bell Helicopter Textron Canada Limited*, (2012)

[7] U.S. Department of Transportation, Research and Innovative Technology Administration,” Aircraft Source Noise Measurement Studies-Summary of Measurements, Data and Analysis”, *Final report,* (2010)

[8] M.W.Lowson, J.B.Ollerhead, “Studies of helicopter rotor noise”, *Usaavlabs technical report 68-60*, (1969)

[9] Clark County Department of Aviation, “Helicopter Noise Analysis”, *Appendix D*, (2008)

[10]D. Menicucci, “Modeling of Helicopter Generated Noise Levels on the Ground”, *Sandia National Labs*, (2000)



University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

ASPECTS OF DESIGN OF POWER TRANSFORMERS FOR NOISE REDUCTION

Ljubomir Lukic[1], Mirko Djapic[1], Dusica Lukic[2], Aleksandra Petrovic[1]

[1] University of Kragujevac, Faculty of Mechanical Engineering Kraljevo, Serbia, lukic.lj@mfkv.kg.ac.rs
[2] University of Belgrade, Faculty of Electrical Engineering Belgrade, Serbia

Abstract - *Power transformers are in the category of capital equipment of power plants and high voltage electricity distribution networks. Factory ABS Minel Transformers in Ripanj designs and produces (manufactures) power transformers with power up to 400 MVA and voltage level up to 400 kV, by using modern methods of calculation and design. Producers (manufactures) of power transformers perform certification of characteristic types of their products in accredited laboratories and by doing that they gain significant advantage in international tenders. Moreover, international standards prescribe functional characteristics which must be laboratory tested (before delivering each transformer to the customer) at delivery moment of each transformer to the user (customer). Lately, the customers increasingly insist on requirements in respect to noise level of transformers, which are sometimes more strict than those requirements prescribed by the standard, in order to protect working and living environment.*

This paper analyzes the influencing factors and points out the engineering solutions that are applied in design phase (in order) to reduce the noise of power transformers.

1. INTRODUCTION

Power transformers belong to the category of capital electric power equipment for each power system. There are several types of power transformers that determines their application: single phase and three phase power transformers, transformers with and without regulation, start up transformers and distribution transformers, transformers for voltage levels of 110 kV, 220 kV, 400 kV and higher voltage levels of above 1000 kV, transformers with power of 8 MVA, 12 MVA up to 725 MVA and 1000 MVA. Start up power transformers are mounted on hydro and thermal power plants and are directly associated with the generating aggregate, while distribution power transformers are installed in high voltage transformer substations like those of 400 kV/110 kV or 110 kV/35 kV.

The beginning of development of power transformers starts with the 80-ies of XIX century and is directly related to the transmission of alternating current from the production site to the end user. The pioneering contribution to development of power transformers was made by:

- P.N. Jablochkoff (П.Н. Яблочков),
- L. Goulard and J.D. Gibbs,
- S.Z. de Ferrari,
- W. Stanley,
- O.T. Blathy, M. Dery and K. Zipernowsky.

Engineers from Hungarian GANZ-a (Bláthy, Dery and Zipernowsky) got three patents in 1885 for distribution of electrical power using shielded transformer with magnetic core. Since then, transformer as a term is being used and industrial production of alternating current transformers begins.

Although the construction of power transformers in its basis hasn't been changed notably since 1885 until today, some of the significant development results have been achieved in recent decades (Figure 1) in the area of application of new materials, reduction of losses, increment of power and voltage levels, regulation, production technology, testing and maintenance of transformers. All that influenced on the fact that power transformer as we know it today is a modern product whose service life often exceeds 40 years of usage.

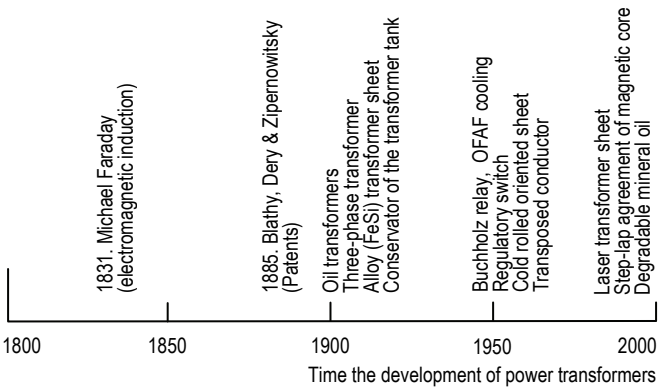


Fig.1 *Development hystory of power transformer's construction*

Today, in addition to functional requirements, very high standards related to protection of human environment are being posed to transformer's constructors. The biggest problems are mineral oils used as dielectric in transformers, which are flammable and eco unfriendly. That's why, in the last ten years, new environmentally better and harder flammable silicone oils, synthetically and natural esters have been developed. Transformer's noise is very important exploitation characteristic of power transformers, which is measured in any final test with methods prescribed by the standards IEC 60076-10 (2001) and IEEE Std C57.12.90

(2006), and at the same time the recommended values of the permitted noise levels by NEMA - National Electrical Manufacturers Association Standards TR1 (1998) must be met. Recommended values of the permitted noise levels of power transformers are defined depending on the power of the particular transformer, test voltage and cooling method (Table 1). With the increase of power of power transformer also increases the permitted noise level (Table 2).

Table 1 *Permissible noise level for 100 MVA transformer with ODWF cooling*

Test voltage kV	350	450	750	900	1175	1300
Permissible noise dB	78	80	81	82	83	84

Table 2 *Permissible noise level for 300 MVA transformer with ODWF cooling*

Test voltage kV	350	450	750	900	1175	1300
Permissible noise dB	83	85	86	87	88	89

Revitalization of hydropower plants, thermal power plants and transmission distribution networks and high voltage transformer substations is usually based on installation of new power transformers with modern construction, which meets all the requirements of international standards. The only Serbian factory of power transformers – ABS Minel Transformatori in Ripanj manufactures power transformers with power of up to 400 MVA and voltage level of up to 400 kV based on its own construction solutions, for EPS (Electric Power Industry of Serbia), EMS (Electric power networks of Serbia), and as well for markets in the region, the European Union, Russia and countries of the former republics of the Soviet Union and countries of north Africa [1]. Currently in the realisation phase is the largest project in the field of electric power in Serbia, the revitalization of HE „Bajina Bašta“ project, which is executed by the Austrian company Andritz Hydro. Within revitalization of all four aggregates of hydro power plant, already two power transformers of power 112 MVA, voltage level of 242/15.65 kV, have been installed. These transformers were designed and manufactured in ABS Minel Transformatori factory in Ripanj, while remaining two power transformers are in production phase (Figure 2).



Fig. 2 *Step-up transformer 112 MVA on H2 unit of HE "Bajina Basta" manufactured by ABS Minel Transformatori Ripanj*

Power transformers of 112 MVA for hydro power plant „Bajina Bašta“ have been examined by Electrical Engineering Institute „Nikola Tesla“ from Belgrade, together with representatives from several accredited European institutions for high voltage tests, during which functional characteristics have been verified according to the standards as well as noise level which power transformers produce during operational time.

2. NOISE OF POWER TRANSFORMERS

The noise that power transformers produce is defined by IEC 60076-10 (2001) standard and is determined by three basic parameters:

- Sound pressure level method (L_p),
- Sound power level method (L_W) and,
- Sound intensity method (L_I).

Sound pressure level is calculated according to:

$$L_p = 10 \lg \left(\frac{p}{p_0}\right)^2 = 20 \lg \left(\frac{p}{p_0}\right) \quad [\text{dB}], \tag{1}$$

where: p – is the sound pressure [Pa] and p_0 – is reference sound pressure $p_0 = 20 \cdot 10^{-6}$ [Pa].

The sound power level L_W is calculated according to:

$$L_W = 10 \lg \left(\frac{W}{W_0}\right) \quad [\text{dB}], \tag{2}$$

where: W – represents the sound power [W] and W_0 – is reference sound power $W_0 = 10^{-12}$ [W].

Sound intensity level L_I is calculated according to:

$$L_I = 10 \lg \left(\frac{I}{I_0}\right) \quad [\text{dB}], \tag{3}$$

where: I – is sound intensity [W/m^2] and I_0 – is reference value of sound intensity $I_0 = 10^{-12}$ [W/m^2].

The sound level A (L_{pA}, L_{WA}, L_{IA}) is frequency adjusted value of calculated sound level that takes into account nonlinear sensitivity of the human ear to different sound frequencies. Human ear is the most sensitive to frequencies around 1000 [Hz], and is less sensitive to lower and higher frequencies. For a particular frequency of sound level A stands:

$$L_{pAf} = L_{pf} + \Delta L_f , \tag{4}$$

where: L_{pf} - is not adjusted linear value of sound level and ΔL_f – is correction to be taken on the basis of empirical values per octave.

The total noise level in the case of multiple sound sources (L_{WA1}, L_{WA2}, L_{WA3}, ...) can be calculated according to the following formula:

$$L_{WA} = 10 \lg \Sigma 10^{0,1 L_{WAi}} . \tag{5}$$

For n equal noise sources of level the total noise level is

$$L_{WA} = L_{WA0} + 10 \lg n . \tag{6}$$

Measurements of power transformer's noise are performed according to IEC 60076-10 (2001) standard, which describes the measurement procedure in great detail. Measurements are performed during tests for short circuit at nominal current at a distance of 300 [mm], 1000 [mm] or 2000 [mm] from contour – the main radiation plane of transformer's trunk. During tests, mainly sound pressure level L_{pA} and sound power intensity L_{IA} are being measured. The main plane of

radiation is imaginary surface that surrounds the transformer's tank and passes through vertical projection of the line around transformer at defined distance (Figure 3). For transformers with natural cooling the measurement points are at a distance of 300 [mm] from the main plane of radiation. For dry transformers, for security reasons, the distance should be 1000 [mm].

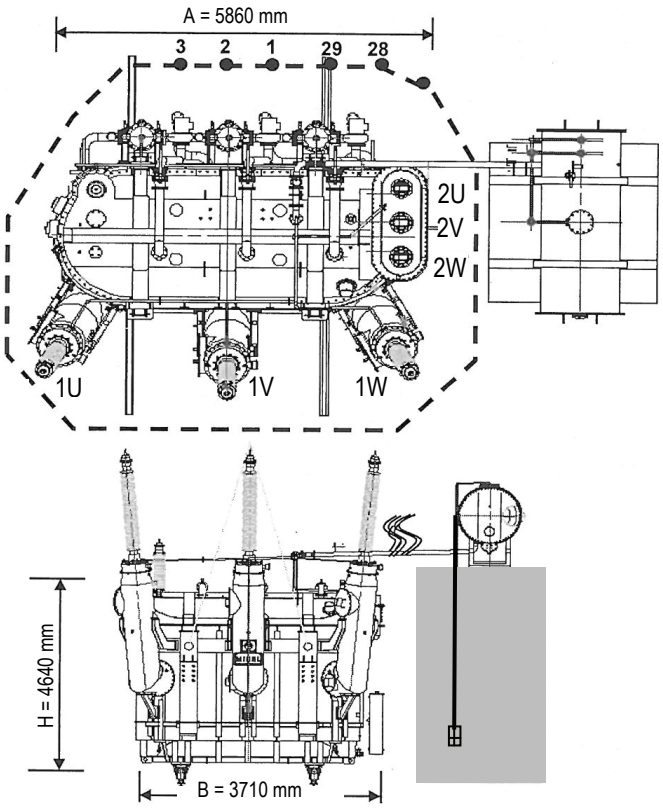


Fig. 3 *Area for noise measurements and placement of measuring points for 112 MVA power transformers*

For transformers with forced cooling measurement points are at a distance of 2000 [mm] from the main plane of radiation. Measurement points are approximately evenly spaced along the edge of the transformer (with step up of 1000 [mm]) provided that there must be no less than 6 measuring points, regardless of the size of the transformer. For transformers with a height of transformer's tank less than 2500 [mm] measuring points are at the half height. For power transformers of greater height measurement positions are at two heights (one at 1/3 and the other at 2/3 of the total height).

3. SOURCES OF POWER TRANSFORMER'S NOISE

Power transformers as fundamental systems for transformation of electricity from one voltage level to another, in the phase of transmission or electricity generation they have several sources of noise, of which the most important are:

1. Magnetic core – where vibrations occur due to the effect of magnetic forces (magnetostriction)
2. Windings – where vibrations of the conductors occur due to electrodynamics magnetic forces and
3. Aerodynamic and hydraulic noise of the cooler – which is generated by the operation of pump units for water cooling or fans for air cooling.

Magnetostriction is a phenomenon that results in a change of dimensions of material being in the magnetic field, and in the case of transformers it results in changes of dimensions of transformer's sheet of magnetic core. The changes are in few μm/m for typical transformer's sheet. The value of magnetostriction depends on magnetic induction (Figure 4), type of transformer's sheet and mechanical strains that arise due to the effect of electromagnetic forces. Magnetic forces are generated within the joints of pillars and yokes of magnetic core.

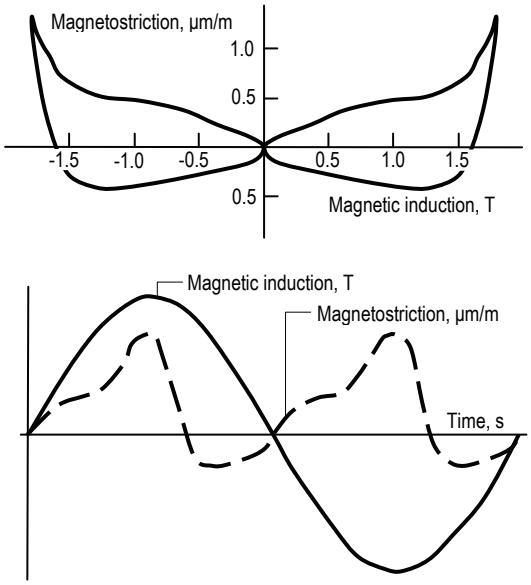


Fig. 4 *Correlation of magnetic induction and magnetostriction*

The frequency of the first harmonic in vibrations of magnetic core' sheets is twice the value of frequency of electrical distribution network, i.e. 100 [Hz] for network of 50 [Hz]. Besides the first harmonic, there are significant amounts of higher order harmonics which resulted as multiplication of pitch frequencies with even numbers of frequencies of distribution network (200, 300, 400 [Hz]).

Noise level of magnetic core is calculated using the following empirical expression:

$$L_{WA}(\text{core}) = k_1 \lg G_{Fe} + k_2 B + k_3 \quad (7)$$

where: G_{Fe} - is the mass of magnetic core, B – is induction inside the core, k_1, k_2 – are empirical coefficients, k_3 – is empirical coefficient that takes into account the type of transformer's sheet, type and construction of the core, frequency, design of transformer's tank.

Electromagnetic forces inside winding conductors, produce axial and radial winding vibrations with pitch frequency twice the frequency of electrical distribution network (i.e. 100 [Hz] for network of 50 [Hz]). Higher order harmonics are insignificant. That noise inside the windings is called load noise, in contrast to the magnetic core noise called the no-load noise. Additional noise is produced by vibrations of terminals from the windings.

Winding noise level for certain load can be calculated using empirical expression:

$$L_{WA}(\text{windings}) = k_1 + k_2 \lg S_r + 40 \lg \alpha \quad (8)$$

where: S_r - is nominal power of transformer, k1 and k2 – are empirical coefficients, α – represents relative load (load current / nominal current).

Aerodynamic noise of the fan significantly contributes to the total noise level of the transformer. The level of fan noise depends on: the speed of fan blades rotation, blade size, construction and number of blades, the ways of setting the fan on the cooler. The frequency spectrum of fan noise is considerably wider than the one belonging to magnetic core. Frequency of the first harmonic is calculated according to the formula:

$$f_1 = n N_b \quad (9)$$

where: n - is the number of revolutions per second, N_b - is the number of fan blades.

Transformer's noise level resulting from the fan noise can be calculated according to the formula:

$$L_{WA}(\text{fan}) = L_{WA,0} + 10 \lg n \quad (10)$$

where: $L_{WA,0}$ – is the noise level of one fan (determined under real operating conditions - the fan on the cooler) while and n - is the number of fans.

The total transformer's noise level is calculated by adding the noise from all sources (magnetic core, windings, fans) with the assumption that all noise sources are independent.

4. DESIGNING THE MAGNETIC CORE IN ORDER TO REDUCE NOISE

There is a multifunction correlation between electrical values and acoustics indicators when designing and calculating the magnetic core of power transformer. While estimating the design parameters of power transformers, various solutions are possible with different values of induction, where increased induction means smaller dimensions of magnetic core, and thus the smaller dimensions of transformer itself. Decreased induction, lower magnetic flux requires a larger amount of material needed and thus the higher transformer's price for smaller nominal power. But also, by reducing induction for every 0.1 [T] magnetostriction and noise of transformer's core reduces for 3 - 4 [dB]. By reducing the induction, noise reduces as well, but at the same time the price of the transformer increases, so designers must find the optimal value of induction from the aspect of competitiveness in the market.

Nowadays, transformer's sheets of 0.23 [mm], 0.27 [mm] and 0.30 [mm] thickness are mainly used when manufacturing a transformer. When applying high quality types of transformer's sheets (HiB-superoriented or ZDKH sheets) with increased price of magnetic core, it is possible to reduce transformer's noise for approximately 3 [dB]. In order to minimize magnetization and idle current losses, and also the noise level, today as a standard solution is used step-lap mode of angular overlap of transformer's pillars and yokes while stacking the magnetic core (Figure 5).

Step-lap lap has several steps unlike the classic lap in one step, which reduces the noise of the magnetic core for up to 6 [dB]. At lower inductions (1.3 - 1.5 [T]) with step-lap lap even greater noise reduction can be achieved (Figure 6). Vibrations of transformer's sheet, which creates noise of magnetic core when magnetic flux passes through it, can be reduced by tightening the magnetic core.

Tightening of yokes with screw connection of the side metal profiles leads to fixing the transformer's sheets in yoke, while tightening of pillars is done by polymer tapes (Figure 7). Half-polymerized poliglas tape is used for tightening the magnetic core, because later while heating the magnetic core it gets fully polymerized and shortened, which leads to very strong tightening of transformer's sheets in pillars of magnetic core. Heating at 140 ^{0}C for 120 minutes polarizes the half-polymerized tape.

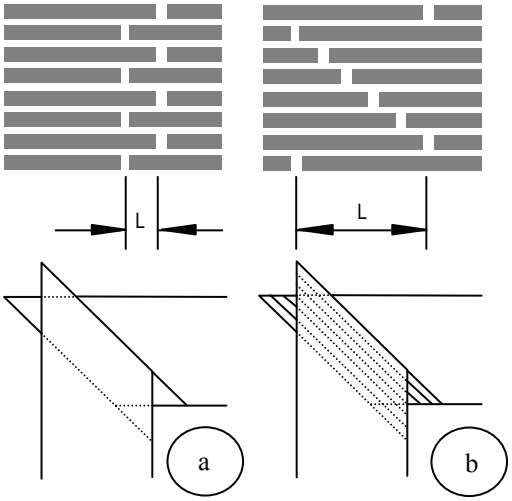


Fig. 5 *Classic and step-lap method for stacking transformer's sheets a) classic method – 1 step, b) step-lap method – 6 steps*

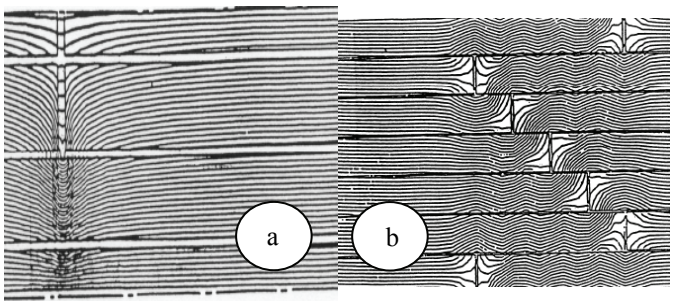


Fig. 6 *Magnetic forces in the area around the overlap of transformer's sheets between the components of pillars and yokes of magnetic core: a) classic method, b) step-lap method*



Fig. 7 *Tighten pillars of magnetic core with yoke being taken off in the assembly process*

By tightening the yokes of the magnetic core with screws made of anti-magnetic material (Figure 8) there is one part of transformer's sheet on the upper surface that remains not tighten because of the yoke's circular cross section (Figure 9). The flat surfaces of the lower yoke are coated with epoxy or wood glue, in order to reduce vibrations of the sheet's ends which are not tighten. The upper yoke must be dismantled because of repair, thus the flat surfaces of the upper yoke are not coated with glue [2].

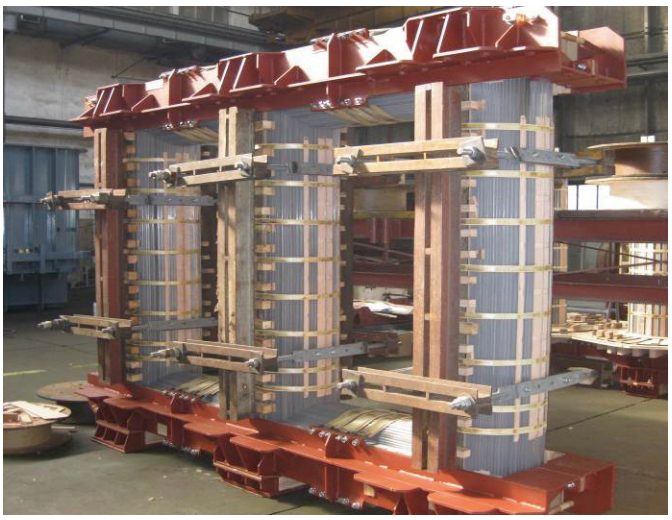


Fig. 8 *Tighten magnetic core*

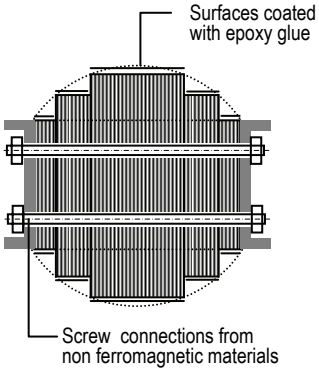


Fig. 9 *The intersection of tighten yoke of magnetic core*

In order to reduce the noise of magnetic core, sometimes the peaks in angles' overhang of magnetic core are being cut, since they are free and they have vibrations due to the flow of magnetic flux. To perform tightening over complete cross section of magnetic core more easily, instead of circular, transformers with rectangular cross-section of magnetic core are rather designed, as one of the solutions to reduce noise. When completed active part of the power transformer is placed in the transformer's tank, it gets further secured with anti-vibration elements that are placed between the magnetic core and the transformer's tank. Besides the fact that reinforcement provides stability of the active part during transport, it also reduces the transformer's noise for about 2 [dB].

5. DESIGN OF WINDINGS FROM THE ASPECT OF TRANSFORMER'S NOISE REDUCTION

With the development of modern methods of CAD design, significant improvements in the design and construction of the transformer's windings are accomplished, using 3D modelling, and especially through simulations and 3D FEM modelling of electrical, electromagnetic and thermal phenomena in transformer's windings, and in different working conditions (Figure 10).

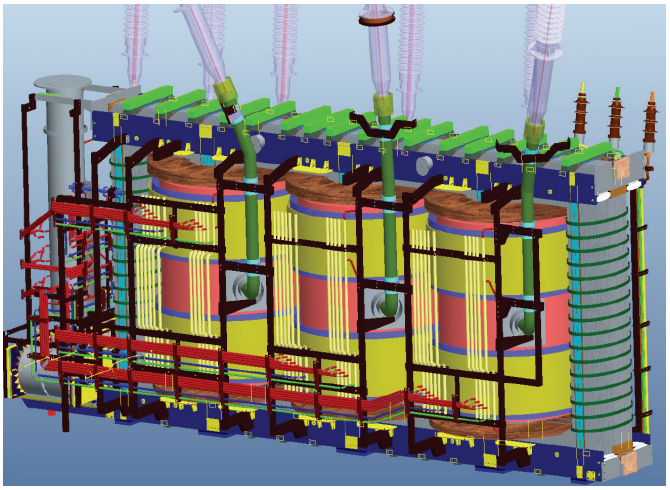


Fig. 10 *CAD project of active part of power transformer*

Windings placed on magnetic core together with the terminal part of the conductors represent the active part of transformer, that is placed in the transformer's tank, which performs drying in vacuum and pouring the transformer's oil. Electrodynamics forces in the windings are with very high intensity, and they create vibrations of conductors in windings that are spaced apart from each other due to oil flow and more intensive cooling. Moreover the terminals are also exposed to vibrations, therefore they firm especially within the active part of the transformer (Figure 11).



Fig. 11 *The active part of power transformer*

By applying modern methods of CAD design, the analysis of electrodynamics forces in windings are carried out, which are correlated with the voltage level of current flow. Electrodynamics forces are particularly intense at short-circuit voltage when they can completely deform windings of the transformer (Figure 12). Modal analysis provides the definition of modal parameters of windings as a mechanical structure, and those are the resonant frequencies, suppression and modal shapes [3].

Resonant frequency is the frequency at which the dynamic excitation creates a critical reaction of windings structure. It is important to identify the resonant frequency because the excitation that is even close to the structural resonance frequency, also produces an adverse effect for the windings.

In most cases, the dynamic excitation generates vibrations of the windings that have high amplitude and can cause damage to the isolation, or in extreme cases - short-circuit voltage, till breaking the conductor and total damage of the windings (Figure 13).



Fig. 12 *Making the windings for 112 MVA power transformer on horizontal winding machine*



Fig. 13 *Deformation of windings due to short circuit*

As the resonant frequencies are associated with the stiffness of the windings, dynamic parameters can be compared with the analytically calculated stiffness and thus they can correct the analytical model of the windings. Winding technique also achieves the suppression effect that allows rapid energy dissipation of vibrations, i.e. windings quickly return to its original condition upon termination of action of dynamic load (Figure 14). Modal shapes represent a way of deforming, moving windings that vibrate at a resonant frequency and make noise (Figure 15).

Transformer's windings are exposed to the radial and axial component of the electrodynamics force. Radial component burden the inner winding on pressure, and external winding on strain. In order to increase the conductor's resistance to pressure, the isolation mounts are being set – lattices that rely on the isolating cylinder, while inside the cooling axial channels at the appropriate distance inserts are being placed. Parts of windings are loaded like a beam with continuous load that makes the deflection.

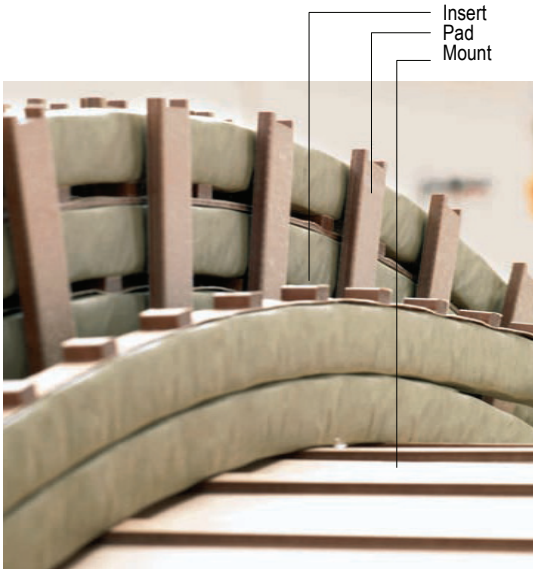


Fig. 14 *Isolation elements that provide rigidity and vibration resistance of conductor in winding*

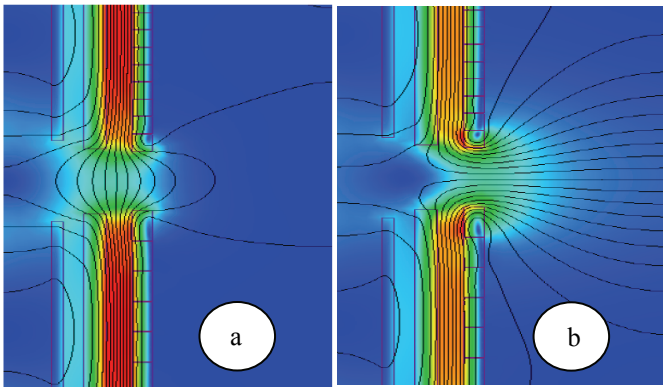


Fig. 15 *Dispersion magnetic field in the space between the windings:*
a) due to harmonics in the phase,
b) due to harmonics in anti-phase

The required number of mounts and inserts is determined by dimensioning of the windings, along with the choice of their size from a series of standardized dimensions, which will provide tightening of conductors that will be less than it is allowed (Figure 16). Mounts causes the local deformation of conductors, which should be also taken into account in the calculation process. Axial forces tend to compress and shift the winding from the current focus (Figure 17). To ensure the durability of the winding's isolation, due to the axial forces, in cooling radial channels of the windings an appropriate number of isolation pads of adequate dimensions are being placed. Dimensioning comes down to determining the required number of pads and the selection of their width from the range of standardized sizes. Specific winding's straining reduction is achieved by increasing the conductor's size, or increasing the transformer's impedance, which increases the amount of used material, and thus the price of the transformer.

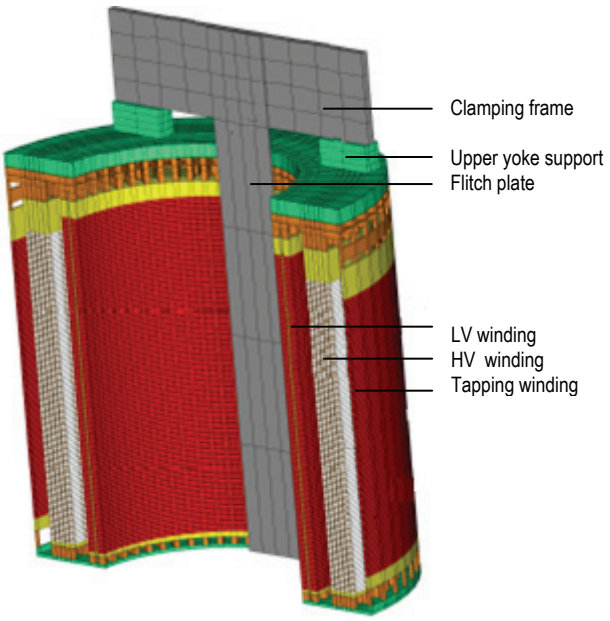


Fig. 16 *Solid model of transformer's winding*

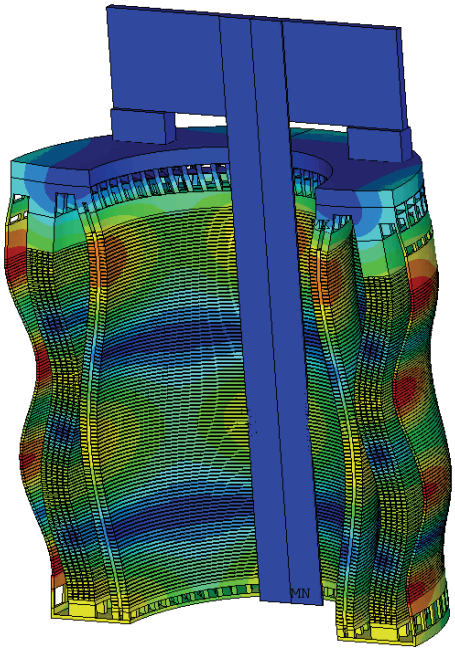


Fig. 17 *Analysis of strainings by MFE method*

Although industrial production of transformers exists already one century, there is still not enough theoretical and practical knowledge about effective measures that can be used to reduce the noise of power transformer's windings. Reducing the noise in transformer's windings is the subject of many scientific research projects, which are carried out in the development laboratories of large companies - manufacturers of power transformers (Siemens, ABB), through researches based on sophisticated numerical methods of modelling (Figure 18).

For large power transformers special kind of transposed conductors for making windings are being made in order to reduce losses in the windings and winding's noise reduction (Figure 19). Transposed conductor consists of several individual specially twisted conductors that provide the same length of the conductor, regardless of the different diameters on windings.

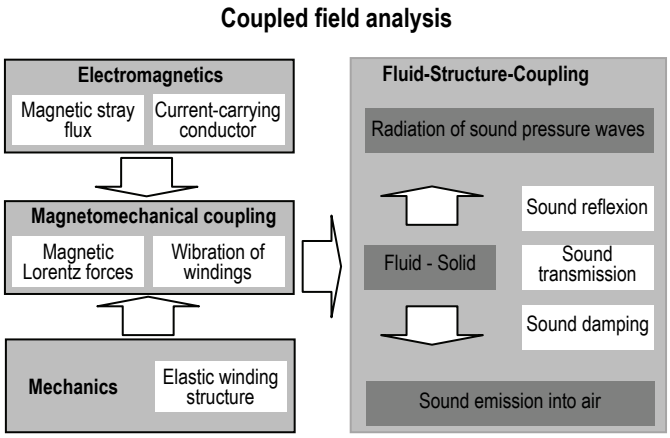


Fig. 18 *Engineering analyzes of windings noise*

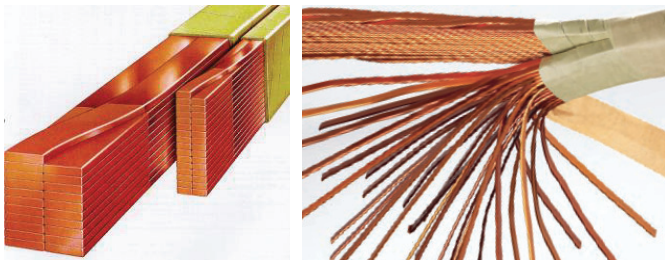


Fig. 19 *Transposed conductors for making windings*

There are still a lot of phenomenological events that are not fully explored in the field of noise generation in the power transformer's windings, so they are still the subject of ongoing researches [4].

6. FAN'S NOISE REDUCTION

Fans are used as an additional transformer's cooling system meaning that they increase the capacity of the cooling system for transformers (Figure 20).



Fig. 20 *Fans on the power transformer*

Fan's noise reduction is achieved with fewer numbers of rotor's revolutions of the fan, but at the same time it reduces the cooling capacity, thus the commonly used fans are with greater number or with larger dimensions blades, in order to compensate the reduced cooling capacity (Figure 21). Reducing fan's noise can be determined according to the empirical formula:

$$\Delta L_{WA} = 70 \lg(D/D_0) + 50 \lg(n/n_0), \quad (11)$$

where: D – is a diameter of the fan, n - number of revolutions per second, p - the number of motor poles.

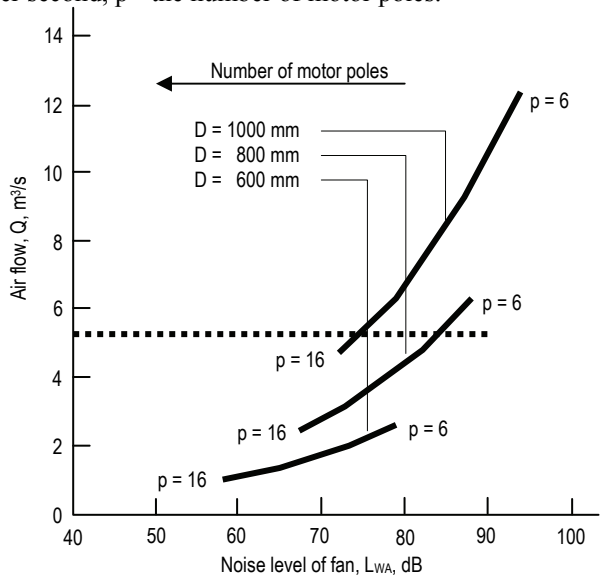


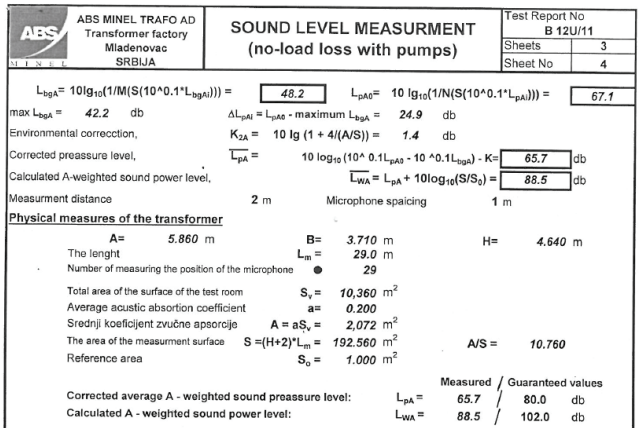
Fig. 21 *Noise level depending on the diameter of the rotor, the number of poles and the cooling capacity of the fan*

In addition to this, reducing fan's noise can be achieved through balancing the rotating masses, quality bearing and stable structure for binding the fan with housing of the radiator for cooling.

7. CONCLUSION

Around thirty years ago, as part of the then known Institute for Machine Tools and tooling (IAMA) in the framework of scientific research program VIBEX - Protection against noise and vibration, within living and working environment, one of direction for the research was the protection of the transformer's noise in urban areas. These surveys also included the distribution transformers that are installed in transformer substations 10/04 kV in inhabited areas. Usually the solution for reducing the noise and vibrations was sought through elastic reliance of the transformer's active part, also with complete transformer substation's isolation techniques with special anti-acoustical materials. Termination of existence of the Institute IAMA and its orientation to the study program of industrial production of machine tools and computer control systems, the research program for protection against noise and vibration has entered into stagnation.

At that time, the noise and vibration studies haven't been focused in the area of large power transformers, which are designed at the factory Minel Transformers in Ripanj according to Westinghouse license. Today in the development of power transformers standards in the field of noise are imposed by major companies from most developed countries in the world, that's why the designers from Minel Transformers factory have developed original methods for calculation and design solutions that fully provide the permissible level of noise and all other functional characteristics required by international standards (Figure 22).


ABS MINEL TRAFO AD
Transformer factory
Mladenovac
SRBIJA

SOUND LEVEL MEASURMENT
(no-load loss with pumps)

Test Report No B 12U/11
Sheets 3
Sheet No 4

L_{bgA}= 10lg$_{10}$(1/M(S(10^0.1*L_{bgAi}))) = 48.2 L_{pA0}= 10 lg$_{10}$(1/N(S(10^0.1*L_{pAi}))) = 67.1

max L_{bgA} = 42.2 db $\Delta L_{pAi} = L_{pA0}$ - maximum L_{bgA} = 24.9 db

Environmental correction, K_{2A} = 10 lg (1 + 4/(A/S)) = 1.4 db

Corrected preassure level, $\overline{L_{pA}}$ = 10 log$_{10}$ (10^ 0.1L_{pAs} - 10 ^0.1L_{bgA}) - K= 65.7 db

Calculated A-weighted sound power level, $\overline{L_{WA}} = L_{pA} + 10\log_{10}(S/S_o)$ = 88.5 db

Measurment distance 2 m Microphone spaicing 1 m

Physical measures of the transformer

A= 5.860 m B= 3.710 m H= 4.640 m

The lenght L_m = 29.0 m

Number of measuring the position of the microphone 29

Total area of the surface of the test room S_v = 10,360 m^2

Average acustic absortion coefficient a= 0.200

Srednji koeficijent zvučne apsorcije A = aS_v = 2,072 m^2

The area of the measurment surface S =(H+2)*L_m = 192.560 m^2 A/S = 10.760

Reference area S_o = 1.000 m^2

		Measured	Guaranteed values	
Corrected average A - weighted sound preassure level:	L_{pA} =	65.7	80.0	db
Calculated A - weighted sound power level:	L_{WA} =	88.5	102.0	db

Fig. 22 *Example of a part of the Certificate for noise measurements of 112 MVA power transformer for HE „Bajina Basta"*

Modelling of the magnetic core, windings and solutions for increasing the stiffness of the transformer's active part is a constant challenge to the designers, who are looking for an optimal solution between functional performances, cost of materials and production costs, bearing in mind that in recent times the world market price for power transformers has been significantly reduced compared to the period of 4-5 years ago, despite the fact that all manufacturers are installing the transformer's sheet of the same characteristics, that the copper price is the same for all producers, that we all use Weidmann isolation materials, Nynas transformer's oil and Reinhausen regulators.

ACKNOWLEDGEMENT

The results presented in this paper are part of research activities within roject TR37020 – „The development of methodologies and means for noise protection of urban areas", which is funded by Ministry of Education and Science, Government of the Republic of Serbia. The authors wish to express their gratitude to Serbian Ministry of Education and Science for support through project TR37020.

REFERENCES

[1] Lj. Lukic, N. Pejcic, "A New Generation of Transformers with Wound Core Patented by ABS Minel Trafo Serbia", Paper on call, *Proc. 7th International Symposium Nikola Tesla,* pp. 51-56, 23. November 2011, Belgrade, 2011.

[2] Lj. Lukić, M. Djapić, "Transportation and Manipulation Processes in the Overhaul of Energy Transformers", *Proc. The Seventh Triennial International Conference Heavy Machinery HM2011, A Session – Railway Engineering,* Volume 7, pp. 25-32, Kraljevo - Vrnjacka Banja, June 29th - July 2nd, 2011.

[3] R. Žičkar, „Optimization in design process of industrial transformers", *Master thesis*, University of Zagreb, Faculty of mechanical engineering and shipbuilding, Zagreb, 2011.

[4] W. M. Zawieska: A Power Transformer as a Source of Noise*, International Journal of Occupational Safety and Ergonomics (JOSE),* pp. 381–389, Vol 13, No 4, 2007.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

NOISE MEASUREMENTS OF THE POWER TRANSFORMERS

Aleksandra Petrovic[1], Ljubomir Lukic[1], Milan Kolarevic[1], Dusica Lukic[2]

[1] University of Kragujevac, Faculty of Mechanical Engineering Kraljevo, Serbia, petrovic.a@mfkv.kg.ac.rs
[2] University of Belgrade, Faculty of Electrical Engineering Belgrade, Serbia

Abstract *- International standards related to functional characteristics of power transformers, very precisely prescribe permitted noise level of transformers in use. Transformer's noise depends on the power, and a number of numerous factors based on the quality of transformer sheet, cooling mode, the magnetic core construction design and technology of the windings. Final laboratory testing of transformers, which are obligatory at each transformer's delivery to the customer, includes noise measurements as well.*

This paper presents the methodology of noise measurements of power transformers in ABS Minel Transformers factory in Ripanj, thus confirming high technological level and product's quality, both in terms of transformation of electrical energy, and from the aspect of environmental protection.

1. INTRODUCTION

High power transformers are installed on hydro power plants, thermal power plants and high-voltage substations and as such fall under the category of capital equipment for the electric power utility of each public power system. There are many types of power transformers that determine their application: single-phase and three-phase transformers, control transformers with and without regulation, step at generator transformers and distribution transformers, transformers for voltage levels of 110 - 400 kV, the power of 8-725 MVA. The highest levels of power in the distribution networks in the EMS in Serbia are up to 400 kV, although in Russia and China there are the power levels of the distribution networks over 1000 kV where are used transformers with power over 1000 MVA. Max power of block transformers which are installed on the facilities of EPS in Serbia is 725 MVA in Thermal Power Plant TENT B in Obrenovac. Large transformers, depending on the power, cost up to 4 million, but their price is recalculated according to the energy loss that occurs during their work. In addition, the termination of the power transformer stops working the whole block or hydroelectric power plants. Cost of blocks delay get huge until a new transformer is produced, so that each hydro or thermal power plant has spare step at transformer for a quick replacement in case of failure. Currently in the implementation phase is the largest project in the field of electric power in Serbia [1], the design for revitalization of HPP "Bajina Bašta" that executes the Austrian company Andritz Hydro. In the revitalization of all four hydroelectric generators, the two 112 MVA power transformers, voltage level of 242/15.65 kV, which were designed and manufactured in the factory in Ripanj Minel Transformers have already been installed and the remaining two are in the production phase (Figure 1).



Fig. 1 *Step up transformer 112 MVA*

112 MVA transformers for HPP "Bajina Bašta" were examined by Electrical Engineering Institute "Nikola Tesla" in Belgrade, with the participation of several European institutions accredited for high voltage tests, with all the functional characteristics verified by international standards. One of the important characteristics of power transformer which is checked in final testing is allowed noise level of transformers in use under voltage.

2. PERMITTED NOISE LEVEL OF TRANSFORMER

For power transformers the main sources of noise are the magnetic core of transformer, coils and forced cooling systems, which can be carried out with fans for air cooling method or with pumps for water cooling method.

Noise level is very important operational characteristic of transformer, which is measured at each final test using methods prescribed by standards [2] IEC 60076-10 (2001) and IEEE Std C57.12.90 (2006). Measured values must meet the recommended values of permitted noise level according to NEMA - National Electrical Manufacturers Association Standards TR1 (1998) or special requests according to the regulations of the national electric power distribution networks. Recommended values of permitted noise of power transformer are defined depending on the power of

transformer, test voltage and cooling modes. With increasing stress levels, allowed noise level of power transformer is increasing as well. For small distribution transformers up to 1000 kVA which are installed in distribution substations in urban areas, the level of allowed noise is up to 64 dB. Most national standards and European countries have stricter requirements regarding permitted noise level than international standards which prescribe the approximate values for transformer manufacturers. For example, requirements of the German, Austrian and Czech power generation industry, in which permissible noise of the distribution transformers of power 50 kVA is 42 dB, and the permissible noise of the distribution power transformers of power 1000 kVA is 48 dB (requirements prescribed by RWE Rheinisch Westfälisches Elektrizitätswerk - 1990), are significantly more stringent requirements than in the most other national electric power systems in the world. For certification of transformer in terms of permitted noise levels, the American National Standards Institute ANSI Standard C89.2 prescribes for distribution transformers up to 9 kVA maximum noise level of 40 dB, and for the power of 301-500 kVA maximum noise level of 60 dB.

According to the recommendations for smaller energy transformers with power of 10 MVA and measured voltage of 350 kV with cooling by mineral oil, transformers allowed noise level according to NEMA recommendation is 68 dB. For the largest power transformers power of 1000 MVA and the measured voltage level over 1300 kV, with combined forced cooling with mineral oil and air, the maximum noise level of transformers is 95 dB. Since the noise level depends directly on the induction or magnetic flux, designer and manufacturer of transformers use the recommended values according to NEMA standard that are commonly given according to method of cooling the active part of the transformer.

The primary source of acoustic noise generation in a transformer is the periodic mechanical deformation of the transformer core and the winding coils, under the influence of fluctuating electromagnetic flux associated with these parts [3]. The physical phenomena associated with this tonal noise generation can be classified as follows:

- The material of a transformer core exhibits magnetostrictive properties. The vibration of the core is due to its magnetostrictive strain varying at twice the frequency of the alternating magnetic flux. The frequencies of the magnetic flux is equal to the power system supply frequency and its harmonics.
- When there are residual gaps between laminations of the core, the periodic magneto-motive force may cause the core laminations to strike against each other and produce noise. Also, the periodic mutual forces between the current-carrying coil windings can induce vibrations if there are any loose turns of the coil.

Some of the other sources of noise in a transformer, such as the cooling fans and the pumps, are considered to be negligible contributors to the far-field noise [4].

3. TRANSFORMERS COOLING SYSTEMS

Type and method of cooling the transformers is very important in terms of reducing temperature and reducing noise of transformer at the same time. Since power transformers can be cooled in different ways, the IEEE 571 200 (2011) standard prescribes a specific system of describing types of cooling.

System of marking and describing the cooling of the transformer is the drive letter with four capital letters, with the first two letters indicate the type and method of cooling fluid circulation which is in contact with magnetic core and windings, and the third and fourth letters indicate the type and method of coolant circulation that is in contact with the external cooler (Figure 2).

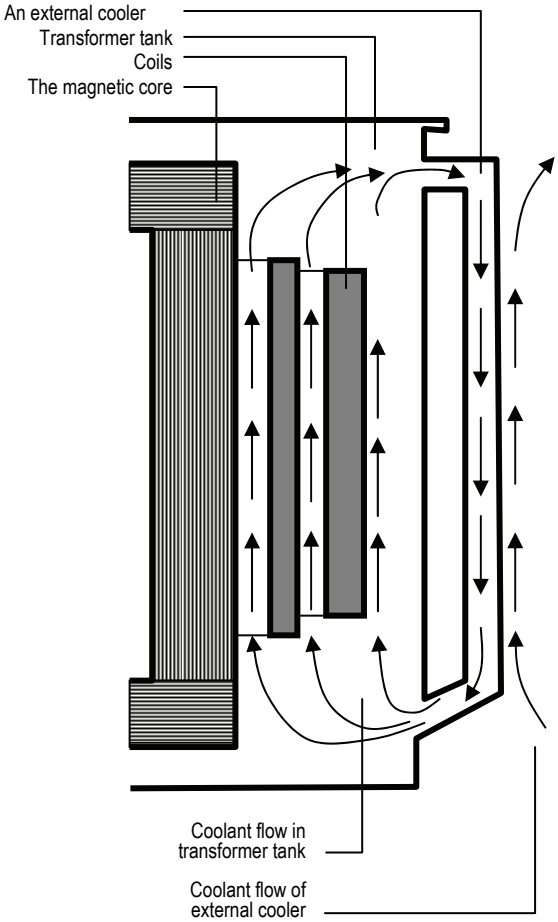


Fig. 2 *Transformers cooling system*

According to the IEEE 571 200 (2011) for the cooling fluid which is in contact with windings the following codes are adopted: A - oil, L - liquid and A - air, and for the method of fluid flow are adopted the following codes: N - natural and F - forced..

For coolant that is in contact with the outside cooler are adopted the following codes: A - air, G - gas, W - water. The most commonly used cooling systems for power transformers are:

- AN - dry transformer without protective housing,
- ANAN - dry transformer with protective housing
- ONAN - oil transformers with the natural flow of oil in the transformer tank and with the air outside,
- ONAF - oil transformers with the natural flow of oil in the transformer tank and with the fan outside,

- OFAF - oil transformers with forced flow of oil in the transformer tank driven by pumps permanently turned on and the outside with the fan,
- ONWF - oil transformers with the natural flow of oil in the transformer tank and with a water cooling pump outside,
- OFWF - oil transformers with forced flow of oil in the transformer tank driven by pumps permanently turned on, and outside with a water cooling pump.

Codes of mode and the cooling type of transformers are constantly supplemented through periodic changes to the standards, due to the development of cooling systems.

4. NOISE MEASUREMENT OF TRANSFORMER 112 MVA

The test procedure is in accordance with IEC Standard 60076-10. At first, the background noise level shall be measured [5]. Then, the transformer shall be powered at rated voltage and frequency under no-load conditions (with the tap-changer selected on the principal tapping), in order to carry out transformer noise level measurements. They shall be performed in several points located around the transformer, placed at a distance of 0,3 m from the machine unless, due to safety reasons or following agreement between supplier and purchaser, the distance is increased to 1 m. Measuring positions shall be spaced at a distance of at most 1 metre one from another; anyway, a minimum of 6 positions is required. The measurements shall be carried out at half the equipment height, if this does not exceed 2,5 m; otherwise, they shall be performed at 1/3 and 2/3 of the component height. After performing transformer sound level measurement, the machine is de-energised and background noise level is measured again; At the end, the final transformer sound level shall result by applying a correction by taking into account the lower background noise level. In case there is a high difference between the transformer and background noise level (>8 dB) no correction shall be applied [6].

Measurement of noise level on power transformers according to IEC 60076-10 (2001-05) can be realized by using three methods [7]:

- Sound power level method (L_W),
- Sound pressure level method (L_p) and
- Sound intensity method (L_I).

Measurement of noise level at the factory ABS Holdings Transformers in Ripanj [8], was performed on the generator step up transformer for block H3 of hydropower plant "Bajina Bašta" in Perućac, with the following characteristics (Figure 3)

- Power of transformer 112 MVA
- High Voltage 242 kV
- Low Voltage 15.65 kV
- Connestion YNd5
- Curent HV 267.20 A
- Curent LV 4131.84 A
- Type of cooling OFWF
- Insulation class A
- Oil weight 25.5 t
- Total weight 124.0 t

Details of measuring instruments:

- Measuring instrument make Bruel&Kjaer, type 2236
- Microphone make Bruel&Kjaer, type 4188
- Acustical Calibrator Bruel&Kjaer, type 4231 (94 dB SPL-1000 Hz)

Test conditions:

- Exitation voltage 15.65 kV
- Frequency 50 Hz
- Temperature ambient 20 ^{0}C
- Humidity 60 %
- Preassure 998 mbara

Physical measures of the transformer:

- Length of the transformer A = 5.860 m
- Width of the transformer B = 3.710 m
- Height of the transformer H = 4.640 m
- Contour length L_m = 29000 mm
- Number of measuring the position of the microphone M(N) = 29
- Total area of the surface of the test room S_v = 10360 m^2
- Average acustic absortion coefficient a = 0.200
- Medium acustic absortion coefficient A = a S_v = 2072 m^2
- Area of the measurment surface S = (H+2) L_m = 192.560 m^2
- Ratio A/S = 10.760
- Reference area S_0 = 1.000 m^2

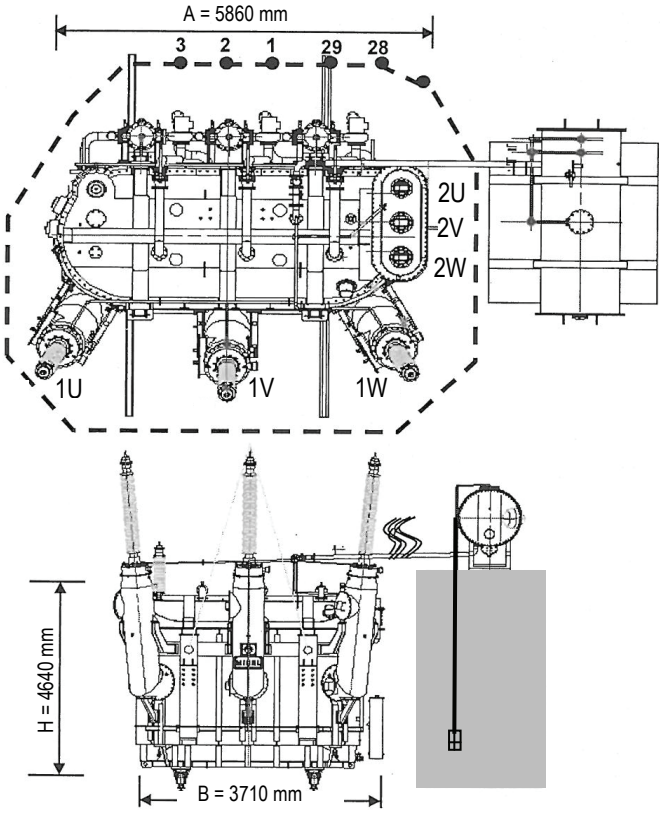


Fig. 3 *Noise measurement zone and layout of measuring points*

The uncorrected average A – weighted sound pressure level L_{pA0}, shall be calculated from the A - weighted sound pressure level L_{pAi}, measured with the test object energized by using equation:

$$L_{pA0} = 10 \lg \left\{ \frac{1}{N} \sum_{i=1}^{N} 10^{0.1 L_{pAi}} \right\} \quad (1)$$

where N is the total number of measuring positions.

The average A – weighted background noise pressure level L_{bgA}, shall be calculated separately before and after the test sequence using equation

$$L_{bgA} = 10 \lg \left\{ \frac{1}{M} \sum_{i=1}^{M} 10^{0.1 L_{bgAi}} \right\} \quad (2)$$

where M is the total number of measuring positions and L_{bgAi} is the measured A – weighted background noise pressure level at the ith measuring position.

The corrected average A – weighted sound pressure level L_{pA} shall be calculated by using equation

$$L_{pA} = 10 \lg \left\{ 10^{0.1 L_{pA0}} - 10^{0.1 L_{bgA}} \right\} - K \quad (3)$$

where L_{bgA} is the lower of the two calculated average A - weighted background noise pressure levels and K is environmental corrected factor.

The environmental correction K accounts for the influence of undesired sound reflections from room boundaries and/or reflecting objects near the test object. The magnitude of K depends principally on the ratio of the sound absorption area of the test room (A), to the area of the measurement surface (S). The calculated magnitude of K does not depend strongly on the location of the test object in the test room. K shall be obtained from equation by entering the abscissa with the appropriate value (A/S)

$$K = 10 \lg \left\{ 1 + \frac{4}{A/S} \right\} \quad (4)$$

Since the transformer has OFWF cooling system, at first we measured the noise level with the transformer cooling system pumps on (Figure 4). It is measured:

- A-Weighted sound pressure levels of the backgraund noise L_{bgAi} (ambient sound pressure level when the transformer is switched off, the sound pressure level when the transformer is switched on and ambient sound pressure level at the end of the testing when the transformer is switched off),
- A-Weighted sound pressure levels L_{pAi} in position H/3m and 2H/3m.

Based on the measured noise values of power transformer 112 MVA (LPAI and LbgAi) with pumps on, values LpA0 = 67.1 dB and 48.2 dB = LbgA were calculated. If there is a large difference (greater than 8 dB) between the LpA0 and measured maximum value $LbgA_{(max)}$ it is necessary to perform the correction. Since the maximum measured value $L_{bgA(max)}$ = 42.2 dB, than $\Delta L_{pAi} = L_{pA0} - L_{bgA(max)}$ = 67.1 – 42.2 = 24.9 dB, indicating the necessity of correction. The value of the correction factor K = 10 lg (1 + 4/10.760) = 1.4 dB, a corrected pressure level L_{pA} = 65.7 dB, while guaranteed values for power transformers 112 MVA is 80 dB. Calculated A - weighted sound power level $L_{WA} = L_{pA} - 10 \lg (S/S_0)$ = 88.5 dB, a guaranteed values for power transformers 112 MVA is 102.0 dB.

ABS MINEL TRAFO AD, Transformer factory, Mladenovac, SRBIJA

SOUND LEVEL MEASURMENT (no-load loss with pumps)

Test Report No: B 12U/11; Sheets: 2; Sheet No: 4

Plan position	A - weighted sound pressure levels of the backgraund noise L_{bgAi}			Plan position	A-weighted sound pressure levels, L_{pAi}	
	At start I	Ambient + pumps II	At end III		Measurments the height of the tank H/3m	2*H/3m
1	40.6	51.9	41.3	1	69.9	67.3
2				2	66.0	64.1
3				3	69.2	62.5
4				4	68.9	65.9
5	39.6	49.7	39.2	5	66.9	67.1
6				6	65.9	70.1
7				7	69.6	64.7
8				8	66.9	69.0
9	39.8	43.9	39.9	9	65.4	65.0
10				10	62.4	62.9
11				11	64.4	62.8
12	39.9	43.9	39.0	12	68.0	64.9
13				13	68.1	67.3
14				14	67.6	64.6
15				15	71.9	66.7
16	40.6	45.1	40.6	16	69.1	67.7
17				17	65.4	65.9
18				18	68.3	63.7
19				19	65.3	62.5
20	41.8	48.2	42.0	20	66.3	69.7
21				21	68.2	70.0
22				22	67.1	67.2
23				23	68.6	66.8
24	42.2	51.6	41.2	24	65.4	66.6
25				25	69.7	68.0
26				26	69.3	68.9
27				27	70.7	67.5
28	40.6	51.6	40.1	28	70.2	69.9
29				29	70.0	68.9

Fig. 4 *The results of noise measurements of transformers with power of 112 MVA with pumps on*

Then the noise level with transformer cooling system pumps switched off was measured following the same procedure (Figure 5). With the pumps off following values were calculated: L_{pA0} = 67.4 dB and L_{bgA} = 40.5 dB. Since the maximum measured value is $L_{bgA(max)}$ = 42.2 dB, than $\Delta L_{pAi} = L_{pA0} - L_{bgA(max)}$ = 67.4 – 42.2 = 25.2 dB, indicating the necessity of correction. The value of the correction factor is K = 1.4 dB, a corrected pressure level L_{pA} = 66.1 dB, while guaranteed values for power transformer 112 MVA is 75 dB. Calculated A - weighted sound power level L_{WA} = 88.9 dB, while guaranteed values for power transformers 112 MVA is 98.0 dB.

ABS MINEL TRAFO AD, Transformer factory, Mladenovac, SRBIJA

SOUND LEVEL MEASURMENT (no-load loss without pumps)

Test Report No: B 12U/11; Sheets: 4; Sheet No: 4

Plan position	A - weighted sound pressure levels of the backgraund noise L_{bgAi}			Plan position	A-weighted sound pressure levels, L_{pAi}	
	At start I	Ambient + pumps II	At end III		Measurments the height of the tank H/3m	2*H/3m
1	40.6	51.9	41.3	1	70.9	71.0
2				2	65.3	64.9
3				3	68.7	64.2
4				4	68.4	66.6
5	39.6	49.7	39.2	5	67.6	66.4
6				6	69.6	69.4
7				7	69.2	66.7
8				8	69.5	64.7
9	39.8	43.9	39.9	9	65.6	66.2
10				10	67.9	63.5
11				11	66.3	63.3
12	39.9	43.9	39.0	12	68.1	64.0
13				13	68.1	68.0
14				14	65.9	66.0
15				15	69.9	66.2
16	40.6	45.1	40.6	16	70.1	67.0
17				17	66.7	67.2
18				18	66.4	66.3
19				19	68.2	64.1
20	41.8	48.2	42.0	20	67.0	69.5
21				21	66.9	69.7
22				22	67.8	68.0
23				23	67.7	65.0
24	42.2	51.6	41.2	24	66.0	65.4
25				25	70.6	69.4
26				26	69.2	68.4
27				27	66.7	69.7
28	40.6	51.6	40.1	28	67.7	68.3
29				29	69.2	71.2

Fig. 5 *The results of noise measurements with pumps off*

The results of measurements at the acceptance tests show a satisfactory noise level of step up power transformer 112 MVA at block H3 of hydropower plant "Bajina Bašta."

5. IMPACT OF TRANSFORMER POWER AND TRANSFORMER PLATE TO THE NOISE LEVEL

Analyzing of the measured values of sound pressure level (L_{pA}) at last 30 power transformers with power from 12.5 to 63 MVA, 110 kV, produced at the factory ABS Minel Transformers in Ripanj, it can be confidently concluded that the increase of transformers power linearly increases the level of sound pressure (Figure 6).

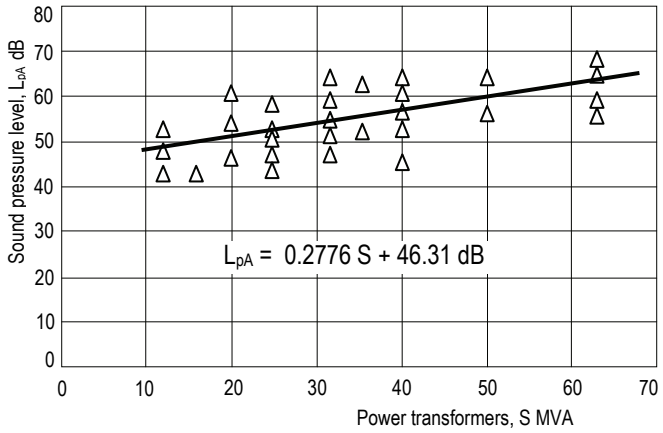


Fig. 6 *Noise measurement zone and layout of measuring points*

Better quality of transformer plate has a higher resistance to impact of magnetostriction, and therefore provides a lower level of magnetic core noise. Analyzing the noise level for a particular value of induction and built-in types of transformer sheet, at transformers with power of 31.5 MVA produced at the factory ABS Minel Transformers in Ripanj, it can be concluded that the lowest noise level insures transformer plate produced by Nippon Steel, ZDKH type (Figure 7).

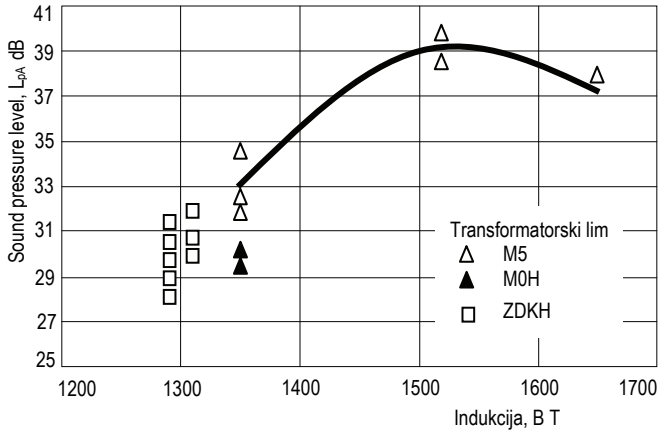


Fig. 6 *The dependence of sound pressure level on the type of transformer plate of magnetic core*

There are conventional type transformer plates and transformer plates that were treated with laser technologies to reduce losses in the iron. Transformer plate M5 is conventional type of transformer plate which is manufactured by Tysen and has a loss about 1.30 W/kg with induction of 1.7 T at 50 Hz. Transformer plates ZDKH and M0H are laser treated sheets with losses 1:03 to 1:05 W / kg. Application of high quality transformer plate, allows a magnetic core construction with a reduced induction for a specific size and power of transformer with reduced losses and low levels of noise, but also increases the cost of the transformer.

6. CONCLUSION

In order to improve aspects of living and working environment protection of power facilities, scientists have developed dry transformers, which don't have transformer tank and don't use any transformer oil, but have an air cooling system or a windings sealed with epoxy materials that absorb heat during heating of magnetic cores. Dry transformers are increasingly used in urban areas because they are environmentally favorable, and have significantly lower noise level compared to oil transformers. Comparative tests show that in the dry transformers up to 1000 kVA noise level is for about 10 - 12 dB lower than for the oil transformers of same power.

Development and improvement of methods of measuring noise at oil power transformers with large power, contribute to the improvement of design methods and manufacturing technology of transformers, and competitiveness in meeting the permissible noise level which modern market of electric power equipment and systems requires today.

REFERENCES

[1] Lj. Lukic, N. Pejcic, "A New Generation of Transformers with Wound Core Patented by ABS Minel Trafo Serbia", Paper on call, *Proc. 7th International Symposium Nikola Tesla,* pp. 51-56, 23. November 2011, Belgrade, 2011.

[2] International Standard IEC 60076-10, Power transformers – Part 10: Determination of sound levels, 2001 – 05.

[3] R. S. Masti, W. Desmet, W. Heylen, *On the influence of core laminations upon power transformer noise*, Proceedings of ISMA, Vibro-Acoustic Modeling and Prediction, 3851- 3862, 2004.

[4] T. Yanada, S. Mmowa, O. Ichinokura, S. Kuchi, Design and Analysis of Noise - Reduction Transformer Based on Equivalent Circuit, EEE Transactions on Magnetics, pp.1351-1353, Vol.34, No4, 1998.

[5] W. M. Zawieska: A Power Transformer as a Source of Noise*, International Journal of Occupational Safety and Ergonomics (JOSE),* pp. 381–389, Vol 13, No 4, 2007.

[6] R.S.Girgis, K.Garner, M.Bernesjo, J.Anger: Measuring No – Load and Load noise of Power Transformers using the Sound Pressure and Sound Intensity Methods – Part – I: Outdoors measurements, *Scientific Conference "Power and Energy Society General Meeting*", 20-24 July 2008, Pittsburgh, 2008.

[7] K.Garner, M.Bernesjo, J.Anger, D.Chu: Measuring No – Load and Load noise of Power Transformers using the Sound Pressure and Sound Intensity Methods – Part – II: Indoors measurements, *Scientific Conference "Power and Energy Society General Meeting",* 20-24 July 2008, Pittsburgh, 2008.

[8] ABS Minel Transformatori – Project and Tehnical documentation, Belgrade, 2012.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to Serbian Ministry of Education and Science for support through project TR37020.



University of Nis
Faculty of Occupational Safety

„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

NOISE CONTROL IN BUILDINGS REGARDING THE CONVERSION PURPOSES - NEW USE FOR OLD BUILDINGS

Milanka Vasić, Marina Jordanović, Ljiljana Jevremović

University of Nis , Faculty of Architecture and Civil Engineering, Serbia; milanka.vasic@gaf.ni.ac.rs

Abstract - *Contemporary relationship betwen building and the architectural profession and preservation of architectural heritage, has fully actualized conversion purposes. Integrated protection of architectural heritage includes the integration and rehabilitation of buildings in the course of modern exploitation of the same object, and the change of its primary functions. The growing number of facilities, which are implemented through the revitalization of an active technical method of conversion applications, has opened a new field of research in the field of noise control and vibration. A well-known five principles of sound insulation, and as experts in this field highlights the existence of zero principle, the "closing room" or "sealing", all of them should be viewed through the prism of conversion and new priorities that can be interpreted as primary, when it comes to this new interpretation throught method of conversion . New function always implies a new form of space. This generally means that the transformation of the existing physical capacity leads to the necessary solutions for new content. One example of this procedure will be represented throught the object of the Academy of Music Hanns Eisler in Belin, as a characteristic example of the inventive addressing issues of noise control, sound protection and insulation for different parts of space, and increased acoustics of some parts of space, due to the specific needs of a new purpose, such ae music school present.*

1. INTRODUCTION

The topic of conversion of old buildings is very wide spread nowadays, and it is analysed from all different sides and aspects. Different cases has a different results, very important role in developeing this model of building recycling all over the Europe, has the new and riseing consciousness of the need for sustaineable developement. In different areas, and building industries as well. Many studies and researchies have been conducted, and some of them as a results revealed that developers preferred new build for city centres private residential development. Though the urban planners of numerous and different urban environments had no preferences, they encouraged the reuse of buildings, but due to a scarcity of suitable redundant buildings for conversion it is inevitable that the city will see new build on the cityscape in future[1].

2. MODERN ATTITUDE TOWARDS BUILDING HERITAGE PRESERVATION

Nowadays it is more and more clear that the relationship of architects and construction experts towards a preservation of the architectural heritage is more activ than in the past. They are determined to make some standard proceduresm through a series of principles and methods of concrete protection. As it is called *the integrated protection*, is one of the top priorities. Their proactive approach in addition to the transformation of the present global socio-political and economic circumstances, fully actualized conversion purposes.

Integrated protection of architectural heritage includes *rehabilitation* and *integration* of the modern buildings in the course of exploitation of the same object by changing its primary functions. An increasing number of objects, that have been revitalized, and their revitalization implemented through technical methods of conversion applications, has opened a new field of research in the area of noise and vibration.

The fact that this method of revitalizeing old buildings, so they can change their original purpose, has given new meaning to these objects with multiple meanings transforming experience.

When it comes to choosing a new purpose for such facility, a significant number of factors must be taken into account when considering all possible solutions. Finally, with reference to the broader context of the urban structure in which the facility, as well as the factors that arise from the general condition and needs of the local community, the facility has been awarded a new purpose.

The reasons that lead to conversion, as the most efficient method for revitalization of an object, but they are handy and refer to those objects that have a certain architectural, or historical value, or sometimes those are fine examles of industrial heritage, etc. Sometimes there can occur rarely and pragmatic reasons, in the case of relatively solid object, which is the original function ceased. Then reasons for conversion are mainly based on the changed conditions of social, political, demographic and social parameters in a single community, or changing of wider scale, which then consequently lead to successive changes of content objects.

New functions always involves a new form of space. This generally means that the transformation of the existing

physical capacity of interior acquire the necessary solutions for new content.

As an example of this procedure will serve School of Music in Berlin. The school is a typical example of the inventive resolving the issue of noise control, sound insulation and insulation of different parts of space, acoustics and increased space for some parts, due to the specific needs of a new purpose, what the music school must have had.

3. CONVERSION PROCESS

After extensive testing state of the structure, where it will be applied to the conversion, in which primarily examines the condition and stability of the structural system and its elements. Then it determines the degree of preservation and detection of possible damage, as well as the required level of remediation of existing structural elements. The project will be based on data obtained in a previous study, with the objective new recognized needs, with the aim of allocating new dimensions of a composition to an existing object, sets down the steps and stages to be undertaken. Constructionally stabilized building is one of the main issues, and also repairing and upgradeing, changeing, and in this sense to incorporate new design elements in the existing structure and building, completely new.

Those could be different elements, such as floor joists, walls and openings, and often a part of rebuilt structure, which aligns with the existing architecture of the underlying object.

"The feasibility of a concept must be verified in detail at critical points, for example where a new staircase is planned, where walls are to be removed and for the routing of buiding services. This shoud be undertaken at the concept stage and special attention shoul be given to the buildings structural system and to spatial interdependencies."[2]

Regulations, though are very rigid and depending on the type of structure and degree of protection by the Institute for Protection the Monuments. And it has a different approach in relation of the significance of the object, and its monumentality. it has diferent treatement whether it's a building of importance, very important or famous building. Than the Institute provides a legal framework, which in this case designers follow when they are making project for conversion.

What is possible to conclude, when it comes to this type of integrated protection of architectural heritage, there are a great deal of problems which appears in that design to be addressed so the final product of the proccess would be in all aspects good and important features of the underlying objects would be saved and cherished.

4. CONVERSION OF MARSTALL IN BERLIN

When it comes to practical use of all of previously mentioned regulations in order to recommend to your attention one good and succsesfull example. In the next few lines and photos one of the most inventive approach to solveing problem of controlling noise, vibration and especially achiveing high level of acoustic as one of the major goals when it comes to this conversion of once Royal mews, and today the Academy of Music Hanns Eisler.



Fig. 1 *The mews (Marstall) of the Berlin Spree Island, at end of XIX cenury. Today the Academy of Music Hanns Eisler[3]*

4.1. *History of the object*

The former symbol of power Hohencola, mews (Marstall) of the Berlin Spree Island (Fig.1), after several different changes, get a new function as the Academy of Music Hanns Eisler and it moved in on april, in 2005. (Fig.2),Facility has undergone several re-appropriation, to do so after a century turned into the Academy of Music. **Error! Reference source not found.**

Behind the facade of the architect Ernst von In, who between 1898. and 1900. modernized the facility and significantly expanded by decades of changes have taken place in the interior after which not much left of the previous splendor.**Error! Reference source not found.**



Fig. 2 *Photo taken during the reconstruction of object, the Academy of Music Hanns Eisler, Berlin [8]*

After numerous changes of contents, at the 1998. the authorities made a public competition. This competiton won the *Berlin bureau Anderhalten Architects* , with its brave concept that the usable area of the building could quickly be doubled. This was possible becouse upper floors were subsequently received three levels of gallery space more, the area which was interpolated, (Fig.3)becouse the some levels was almost 6.65m high.



Fig. 3 *Academy of Music Hanns Eisler, section [8]*

5. PRINCIPLES OF SOUND INSULATION IN THE CONTEXT OF CONVERSION

There are five basic principles of sound isolation of closed spaces even though the experts suggest that there should be recognised as neutral principle, first of all five known, and it is the "full closure of the space." Unfavorable results of the application of the most advanced insulation systems and material wont be accomplished if the space is not completely isolate, or "sealed", as it is explained in the prime principle.

5.1. *First principle*

First principle is the *principle of the mass*. Every sound disorder will tend to cause tremors of any possible obstacle, so far as it is inert, and has a greater mass. In other words: If the wall is heavier, it'll be more difficult to make it vibrate. This principle is hardly applicable in cases of intervention in the existing building, especially when it comes to new construction of interpolation, and as a rule, designers usually chose some lightweight and prefabricated construction. The reason for that metter is becouse that kind of construction could be eareasier and more successful incorporated into the existing construction structure system, such materials has faster performance, a new use will occur more quickly, thus saving resources is higher. And this is always one of the most important

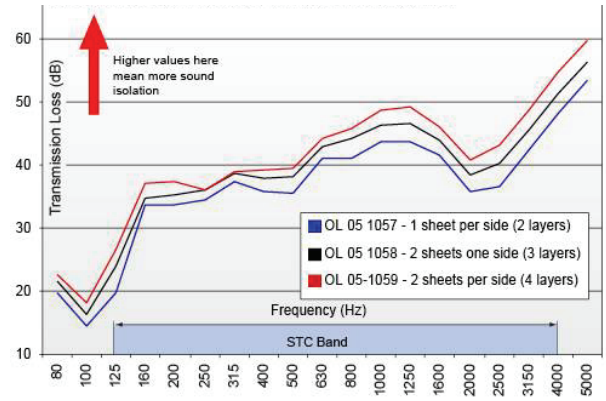


Fig. 4 *Effects of adding mass to the common wood stud wall [4]*

So, just looking at isolated ground system partition, simply zoom in and add weight, by itself will not have a notable effect (Fig.4), except in combination with the other four principles.[5]

5.2. Second the principle of separation

The *principle of separation* , or air pocket and the absence of rigid connections in the strtucture of the walls. It is one of frequently respected principles. The principle says that creating an air pocket between the two layers of wall with as little physical connection of the two layers is achieved by improving the sound insulation. Inserting some elastic, flexible barrier material between layers, forming a double partitions with staggered columns, with the result that will weaken one of the sound passing through the air pocket and the rest will be significantly reduced when it struck, for an example inserted insulation of some kind of absorption materials (wool, polystyrene etc.) [4]

This principle coud be easily appicable in cases when the huge intrior of object should be devided in to smaller parts. By useing some kind of flexible barrier material between layers of new walls, which could be made out of different materials and conected in non rigid connections, the controle of noise and vibration woud be better. This could be easily achieved even with some light weight materials also easy to assemble. However, this principle is not universal and is very dependent on the frequency.

This principle is used in previously presented examle. Becouse air pocket and the absence of rigid connections did a great job for expected acoustics in musical school.

5.3. Third absorption principle

The absorption principle is one of the most widespread and well-known principle that is often identified with complete sound insulation. Inserting an absorbing material such as mineral wool, polystyrene and some others alike. One part of the sound is lost within the structure of the material and not spread further. Some of the benefits of adding these materials in the cavity surely is lowering the value of the resonant frequency of the system.

However, at very low frequencies, the effect of addition of these materials does not make much sense or difference. In fact, if you put a plate of plain fiberglass in of front speakers you'll notice that the sound level is significantly reduced, however, if the same material set in front of the woofer or subwoofer virtually no effect in reducing the sound will be noticed.

The solution of reduceing the noise certainly not getting selected solely on account of the material contained within the partition wall or ceiling. Absorption materials only in combination with other elements and the principles of sound protection play an important role in the overall reduction of the level of transmitted sound.[5]

As we will see in the example to be presented in this paper**,** absorption materials can be of very different kind. Even a plain polyacrylic balls (Fig.5, Fig.8), could serve as absorber and reflector, and they are filled with mineral fiber and partially perforated to increase.



Fig. 5 *Example of sound proff and also acoustic classroom, with polyacrylic balls, at the Academy of Music Hanns Eisler, Berlin, Germany[3]*

5.4. Fourth the principle resonate

This principle sayes that every mechanical system has its own frequency of oscillation, and at the time when the frequency of the forced oscillation technique (in this case sound) coincides with the frequency of oscillation of the

system, then the amplitude of oscillations increases linearly with time. The volume is exactly proportional to the amplitude of the oscillation [4].

There are two main directions in solving the problems of resonance:

a) fading or attenuation - useing resilient materials that reduce or attenuate the amplitude of oscillation and thus reduce the level of sound that extends from the other side oscillating components;

b) move the resonance point - useing the proper combination of principles 1, 2 and 3 resonant frequency can be shifted to lower values. It is important to emphasize that the phenomenon of resonance and a very important factor for the duration of excitation of oscillations, taking into account that the resonance is during the time of excitation amplitude oscillations gradually increases the excited element **Error! Reference source not found.**.

It could be easily achived by carefful and proper chooseing of contemporary and new materials. It is already known that every new generation of insolation materials is better, improved and more resiliant in order to last longer and be more adaptable.

5.5. The fifth the principle of conducting the sound

The last of the five basic principles. It refers to the *indirect conduction of sound* through the structural elements that actually are not immediate conected to partition elements. As we see, the sound in the adjacent room is not transmited indirectly, (Fig.6a, 6b) except directly through the partition wall, and transmits the vibrations through the ceiling and floor. Conducting longitudinal waves through the structural elements of the floor and ceiling and doors and windows.

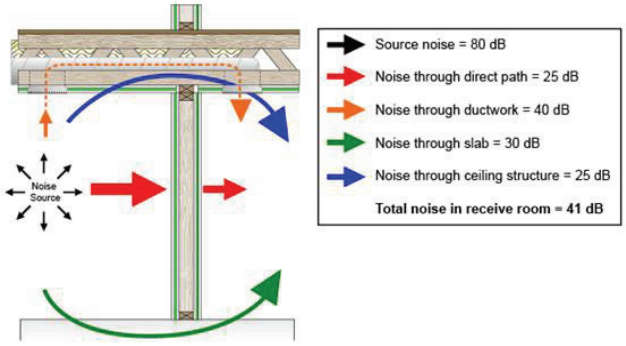


Fig. 6a *Example of sound propagation, in the vertical view, with some values of noise leve, in dB*

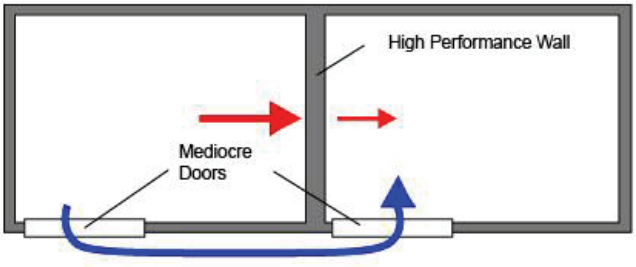


Fig. 6b *Example of sound propagation, in the horizontal view[4]*

Moreover, very often much of the noise goes through right channels and heat insulation will be the worst link in this chain. Namely, any further intervention and improving sound insulation of partition wall wont give any further effect, if we do not cut off the channels that conduct sound through the ceiling construction and floor covering .**Error! Reference source not found.**

This can be done by inserting a mechanical barrier channel, vibration dampers and it is important to do this intervention on the side of the noise source.

5.6. General recommendations based on five principles

Based on previous analyzes of all of five principles of the sound insulation, it is clear that a good sound insulation can reduce noise and vibration. And project has to have good performance at the end if the designers take a consideration of essential elements of the good design and safety measures when it comes to sound insulation. These following are general recommendations:

- Increase the mass
- Mechanical separation
- Insert the Absorber
- The mechanical damping

Everything that we do and what the effect has no essential improvement of some of the above items, wont have a measurable impact on the overall effect designer wish to achieve with his project.



Fig. 7 *The interior of one hall, showing the walls covered with polyester covers, originally made for fluorescent ceiling lamps [3]*

"Sound insulation is a component of general building quality. The structure of sound energy paths between rooms influencing the sound insulation is very complicated problem in some buildings. Sound insulation is important in the designing stage, and its controling by measurements in new buildings is obligatory."[5]

6. INNOVATIVE ACOUSTIC SOLUTION

An interesting solution is the acoustic optimization of interior space, which is done with the help of big bags of insulating material. In accordance with the advice of experts in the field of acoustics, architects devised a new system of porous bricks, so that the space between the walls woud be filled with polyester sphere, covers originally made for fluorescent ceiling lamps. Originally planned as a modular boxes, clasrooms were built in dry construction system for practical

reasons, and mainly because of low cost. And with priority given to separate classrooms for exercise and their ventilation systems. Interior acoustic optimization was performed using a large bags of insulation material, which were named "pillows" only for remarkable similarities with the pillows that we know. The futuristic look is achieved by using polyester spheres, even as a wall cover (Fig. 7, Fig.8), which are nothing more than simple commercially available polyacrylic ceiling lamp covering. At the same rooms, polyacrylic balls were used as absorber and reflector, and were filled with mineral fiber and also partially perforated to give as much contribution to acoustic comfort of the venue. In large straw for rehearsals and the concert hall of the dome filled with lots of plastic balls (Fig.5, Fig.9), that occupy the upper space of the gallery hall ballet. And they are made in three sizes, with diameter betwen 1.8 m and 2.5 m. **Error! Reference source not found.**

The variety of sizes of these balls made an impression of suspended ceiling, and lights behind them are hidden so their role was dual. Students were given the impression of wider space, and the new material yet achieves the former atmosphere of the period of "crystal chandeliers". The old conservative "Marstall" reconstructions unexpectedly eased in the interior, while architects preserve the contextual environment of the remaining buildings. The fact is that this is a good concept, at least temporarily, ensure the preservation of the once Marstall, now the Academy of Music Hanns Eisler, Berlin, Germany.



Fig. 8 *The interior of one of the halls at the Academy[8]*

7. CONCLUSION

When we talk about the insolation and noise and vibration managing in old the objects with new content, it is a serious problem. Designer and all of creative team must be aware of huge responsibility when it comes to desigens of solveing those known, recogniyed and all of anknown tasks, that may occurred during the proccess of conversion the object. Especially if in qestion is an protected object, as the authors of the paper regardeing to problem of intervention in historical venues emphasized:

"One task that occurs in acoustic design rooms can be retrieved acoustic response of some historic hall. Such objects as cultural monuments due to its value are under some form of protection of the state. Design possibilities of action in such circumstances are very limited." [7]

And after all is already said, as a conclusion let me give a short review in one sentence, useing an old saying. When it comes to the problem of conversion, the objects sould be *cherished or it will perish*. But designers must take into account a problem of noise and vibration control during the proccess of designeing with great responsibility.

What it really means, in the metter of of concrete actions? This means that the problem of new requirements and conditions that project of conversion should fulfilled is to be taken seriously. Sometimes it can be solved in some anusuall manners, as we finde out in the example of the Academy of Music Hanns Eisler. Although, more appropriate and more common is to solve problem by useing new materials and construction solutions to enforce and stimulate fast execution of works and completion of the project. Because, as another saying is popular - *time is money*. We are witnessing today that it has become an imperative, that in its fullest sense reflect the situation in the construction industry.



Fig. 9 *One view of interior , showeing the polyester calotte, one of innovative solutions for acoustic optimization of the space[8]*

REFERENCES

[1] Lee Rhodes, Sara Wilkinson, "New build or conversion?: Stakeholder preferences in inner city residential property development", Structural Survey, Vol. 24 Iss: 4, 2006., pp.311 - 318

[2] Cramer, Johannes. Breitling, Stefan, **Architecture in existing fabric**, Planning Design Building, "Preparatory ivestigations", 2007., 31-42p.

[3] DB, Deutsche Bauzeitung, 10/ 2005., Academy of Music Hanns Eisler in Marstall

[4] http://www.zvucnaizolacija.com

[5] Mijić, Miomir: **Akustički komfor**, poglavlje u knjizi ″Održavanje, obnova i rekonstrukcija objekata višeporodičnog stanovanja i poslovanja″, Arhitektonski fakultet Univerzitetau Beogradu, Beograd, 2007

[6] Mijić, Miomir, **GRAĐEVINSKA AKUSTIKA,** ETF**,** Beograd, http://www.scribd.com/doc/26933714

[7] Mijić, Miomir, Pavlovic-Sumarac, Dragan, Intervention in historical venues,Example of Opera Hall in Ljubljana, ETRAN Conference, 2010

[8] http://elizabethquigley.files.wordpress.com



University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

APPLICATION OF THE REVERBERATION TIME FORMULATIONS IN ORDINARY ROOMS

Ana Petelj [1], Miodrag Hadžistević [1], Aco Antić [1], Janko Hodolič [1]

[1] University of Novi Sad, Faculty of Technical Sciences, Serbia, petelja@uns.ac.rs

Abstract - *The reverberation time formulations are designed for prediction of parameters in diffuse sound field. In the reverberation chamber method Sabine's formulation is used to determine the absorption coefficient of the sample. Reverberation chamber has approximately diffuse sound field but tested material sample makes sound field less diffuse if sample has a much higher value of absorption coefficient in comparison to absorption coefficients of chamber surfaces and if sample is of significantly lower surface area relative to the total surface area of the chamber, which is often the case. One of the main characteristics of diffuse sound field is that reverberation time is the same regardless of the position of sound source and microphone. This phenomenon is observed in ordinary room with surfaces of similar values of absorption coefficients when the room is empty, i.e. without tested absorbent sample; Therefore there are made measurements of reverberation time with and without absorbent sample. Measured values were used for comparison with calculated values using reverberation time formulations and for obtaining absorption coefficients in order to determine the deviations of the calculated absorption coefficients to the real one. Certain conclusions are made based on obtained results.*

1. INTRODUCTION

Due to the existence of reverberation chambers in a small number in developing countries, there is a need for the determination of acoustic properties of materials in non-laboratory conditions. There is also a lack of "expensive" software for modeling the propagation of sound in the room, which imposes need for alternative solutions. For these reasons, this paper examines the possibility of using the reverberation time formulations to predict the reverberation time and absorption coefficients of samples tested in ordinary rooms. On the other hand, despite the long practice of measuring in reverberation chambers, for the same sample absorption coefficient can range up to 0.4 in two different laboratories, which is a huge error [1]. Two formulas for the reverberation time are chosen. The first one is Sabine's, which is still widely used and is part of the current standards regardless of the well-known deficiencies. In the case of samples with high absorption it may give coefficient values greater than 1, which are not realistic. Formula used to less extent and recommended by some authors is the Millington's, which does not give values greater than 1 if Millington's coefficients are used. Dance and Shield [2] enabled easy transformation of Sabine's coefficients, which are available in various literatures, to Millington's coefficients, which are available to a much lesser extent, thus facilitating their implementation.

2. METODOLOGY

2.1 Measuring equipment

Excitation of the room for reverberation time measurements were carried out by impulse sound, and the source was balloon whose circumference was around 80cm, which is considered adequate for this purpose [3]. Measurements were made by sound level meter, which has option for automatic calculation of reverberation time.

2.2 Rooms description

Measurements were performed in two rooms of irregular shape. One was a nuclear shelter room (hereinafter referred to as room 1) of area 32.60m^2 and the height 3.25m, and second one was storage room (hereinafter referred to as room 2) of surface 14.15m^2 and height 2.80m.

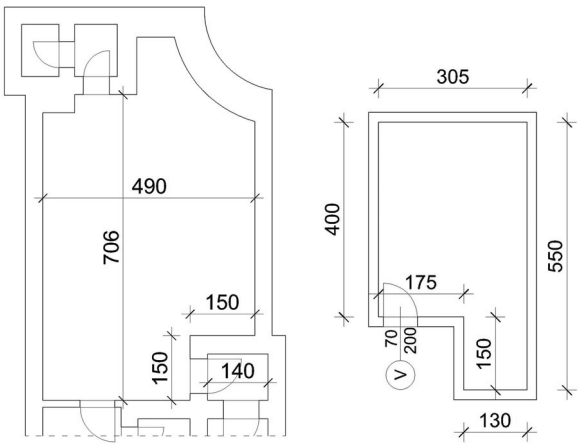


Fig. 1 *Floor plans of rooms*

2.3 The positions of sound source, microphone and absorber and absorber dimensions

Positions of microphones and sources were close to the corner of a room or close to the middle part of the room in both rooms. The minimum distance between microphone, source and reflective surfaces was 1m. The tested sample was glass wool, which was placed in several positions on the floor. Selected positions of the absorber were closer and

further away from the sound source (distances between positions were 30cm), to determine the possible dependence of the reverberation time on the distance of absorber from the sound source. Different surfaces and thicknesses of samples were selected to determine how they affect the deviation of the calculated absorption coefficients from adopted ones from literature sources. In the room 1 measurements were performed with absorber samples of 10 cm layer thickness and area of 0.5, 1.0 and 1.5m^2, and in the room 2 measurements were performed with absorber samples of 5 and 10 cm thicknesses and 1.2m^2 area .

2.4 Absorption coefficients and reverberation time formulas

Tables 1 and 2 show the materials of which rooms parts were made, adopted Sabine's coefficients for a given material, as well as the values when they are converted to Millington's coefficients via formula [1]:

$$\alpha_m = 0.071\alpha_s^3 - 0.416\alpha_s^2 + 0.99\alpha_s + 0.005 \quad (1)$$

Table 1 *Absorption coefficients for room 1*

Material	Sabine's α	Millington's α
Door, steel	0.073333[4]	0.075391
Floor, ceramic tiles	0.013333[5]	0.018126
Walls and ceiling, concrete	0.018333[1]	0.023011
Person	0.435417[6]	0.363055
Glass wool (10cm)	0.85[1]	0.589543

Table 2 *Absorption coefficients for room 2*

Material	Sabine's α	Millington's α
Walls, plastered concrete blocks	0.046667[7]	0.05030126
Floor, concrete	0.0275 [1]	0.031911877
Door, wood	0.06666667[1]	0.052836073
Ceiling, wood	0.03833333[1]	0.045532914
Person	0.435417[6]	0.363055052
Glass wool (10cm)	0.85[1]	0.589542875
Glass wool (5cm)	0.668333[1]	0.502030721

The selected coefficients are mean values of the coefficients for the individual octave bands from 125Hz to 4kHz, since the values for these octaves are available in the literature.

Current standards are based on Sabine's formula [1]. It is well-known that Sabine's formula becomes inaccurate for absorption coefficients larger than 0.2-0.4. In these cases, more precise data gives Millington's formula. The selected coefficients are used to calculate the reverberation time and absorption coefficients via Sabine's and Millington's formulas, which are given below:

$$T_s = \frac{55.3V}{c\sum \alpha_i S_i} \quad (2)$$

$$T_m = \frac{55.3V}{-c\sum S_i \ln(1-\alpha_i)} \quad (3)$$

where:

T_s - reverberation time according to Sabine

T_m - reverberation time according to Millington

V - volume of room

c - sound velocity

α_i - absorption coefficient of room element

S_i - surface area of room element

3. RESULTS

3.1 Room 1

The mean value of the measured reverberation times of empty room was 4.00s. The maximum deviation of the measured reverberation time from the mean value was 0.05s. Reverberation time is also calculated by Sabine's and Millington's formulas. While Sabine's formula (t = 4.88s) showed significant deviation from the measured values, Millington's formula (t = 3.99s) resulted in a slight deviation. Calculated Millington's coefficients were significantly deviated from the adopted coefficients, and in the way that decreasing sample surface result in increasing deviation. However when the side surfaces of the samples were included in calculations, the deviations were minor. When it comes to Sabine's formula, the deviations are reduced by including surfaces of edges in the calculations, but they were still non-negligible. Table 3 shows the adopted and calculated absorption coefficients for the room 1.

Table 3 *Adopted and calculated absorption coefficients of samples for room 1*

	Sabine's α			Millington's α		
Sample surface (m^2)	Adopted	without side surfaces of sample	with side surfaces of sample	Adopted	without side surface of sample	with side surfaces of sample
0.5	0.85	2.90	1.81	0.59	0.74	0.57
1.0	0.85	1.97	1.41	0.59	0.70	0.58
1.5	0.85	1.62	1.21	0.59	0.67	0.57

Since the Millington's formula showed better results, analysis of the octave bands were done using this formula. Since the available literature absorption coefficients are for the octave bands from 125Hz to 4kHz, these bands were analyzed. Prediction of reverberation time for individual octaves of empty rooms using the formula resulted in large deviations. The smallest deviation was for the 250Hz octave band, where the calculated reverberation time was 0.27s shorter than measured one. The maximum deviation was for the 4kHz octave band, where the calculated time was longer by nearly 2s than measured one.

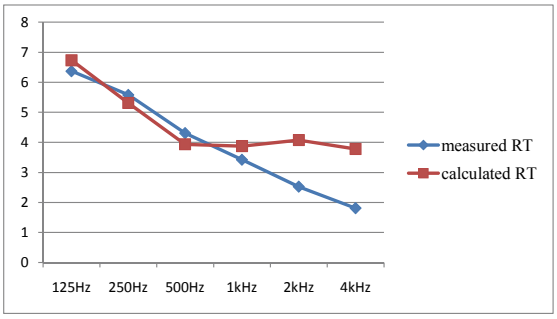


Fig. 2 *Measured and calculated reverberation times in room 1 without absorber*

Figure 2 shows that higher the frequency shorter the measured reverberation times in empty room. This is not the case with calculated reverberation times due to the similar values of adopted absorption coefficients for 500Hz to 4kHz frequency bands.

In most cases, large deviations of calculated absorption coefficients relative to the adopted ones were noticed. Only for the 125 and 500 Hz octave bands the calculated coefficients are similar to adopted ones. For the band whose center frequency is 250Hz obtained values were lower than adopted coefficients, while for the octave bands 1kHz, 2kHz and 4kHz the calculated coefficients were higher. A general increase in the calculated absorption coefficients with increasing frequency is observed. The exception is the 250Hz band coefficient.

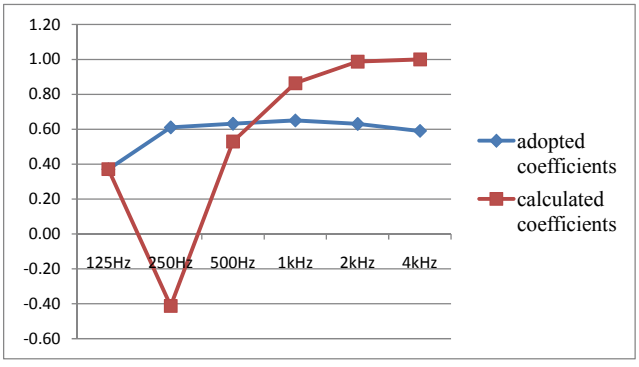


Fig. 3 *Absorption coefficients of sample of surface 0.5m²*

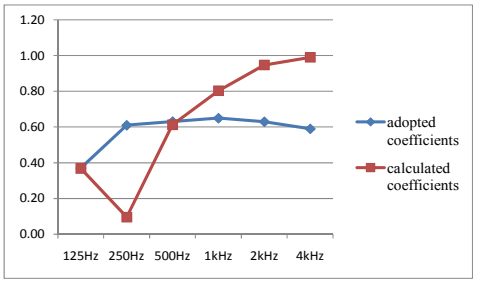


Fig. 4 *Absorption coefficients of sample of surface 1m²*

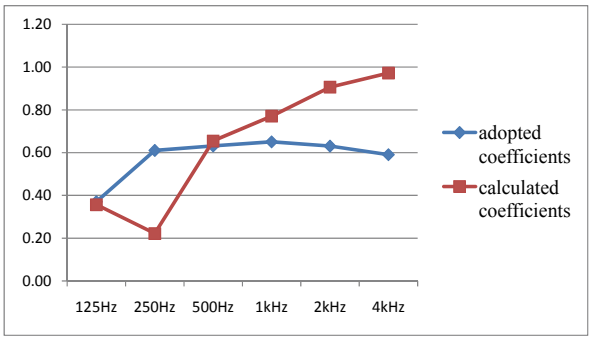


Fig. 5 *Absorption coefficients of sample of surface 1.5m²*

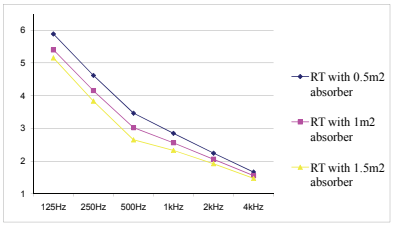


Fig. 6 *Measured reverberation times with absorber samples*

Figure 6 shows decrease of measured reverberation times for all three samples as central frequencies are higher and there are no significant deviation of reverberation time for 250Hz frequency band. Therefore measured reverberation time is not reason for extremely low calculated absorption coefficient for this band. Since sound velocity and room volume are constant, adopted values of absorption coefficients are cause for this deviation.

3.2 Room 2

The mean value of the measured reverberation times of the empty room was 1.21s and there was no deviation of measured times from mean value. Sabine's formula resulted in a reverberation time of 1.26s, and the deviation was not significant (0.05s). Obtained reverberation time by Millington's formula was 1.15s, and deviation is negligible as well (0.06s).

For the absorption coefficients, the situation is similar to the room 1. Small deviations of the calculated Millington's coefficients were obtained by including lateral surfaces of the samples in the calculation. For Sabine's coefficients, the deviation was reduced by including surfaces of edges in the calculation, but it was still significant. Table 4 shows the adopted and calculated absorption coefficients for room 2.

Table 4 *Adopted and calculated absorption coefficients of samples for room 2*

Sample thickness (cm)	Sabine's α			Millington's α		
	Adopted	without side surfaces of sample	with side surfaces of sample	Adopted	without side surface of sample	with side surfaces of sample
5	0.67	1.07	0.91	0.50	0.56	0.50
10	0.85	1.53	1.12	0.59	0.72	0.61

Analysis for individual octave bands are made only by Millington's formula from the reasons mentioned above. The observed deviations are large for reverberation time of empty room in most cases. The least is a deviation of 500Hz band, (0.03s) and the biggest for 125Hz octave (0.66s).

The adopted absorption coefficients are larger than the calculated for 125 and 250 Hz octave bands for both sample thicknesses. Within other bands adopted absorption coefficients are smaller than calculated ones. A general increase in obtained coefficients with the increase of central frequencies is observed in room 2 as well.

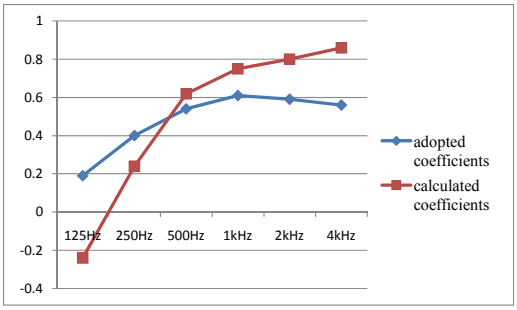


Fig. 4 *Absorption coefficients of sample of thickness 5cm*

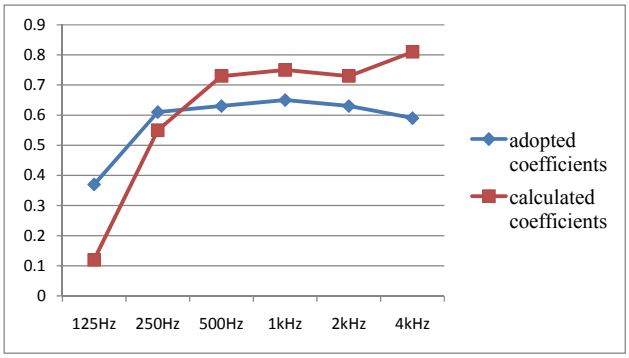


Fig. 5 *Absorption coefficients of sample of thickness 10cm*

3.3 The dependence of the reverberation time of the distance of sound absorber from the sound source

In room 1 measurements were performed with samples placed at different distances from the source. Different correlations between reverberation time and distance are obtained. It was observed that as the sample is further from the sound source, the reverberation time is greater only for the sample of surface 1.5 m^2. Due to the lack of a clear dependence of reverberation time and absorption coefficient on the distance of sample from the sound source, it has not been further analyzed.

4. CONCLUSIONS

Sabine's formula did not result in good approximations of reverberation time and absorption coefficients of samples in most cases. Application of Millington's formula in combination with Millington's coefficients taking into account the lateral surfaces of the samples has resulted in small deviations from measured values, but it is limited to determination of mean reverberation time and mean absorption coefficient of the sample for the frequency range that includes the octave bands from 125Hz to 4kHz, as application to single octave parameters did not give satisfactory results. Tests included samples of several thicknesses and sizes and rooms of certain dimensions and shapes, therefore additional measurements are required to establish the general applicability of the method.

REFERENCES

[1] J. Cox, P. D'Antonio, Acoustic Absorbers and Diffusers, Taylor & Francis, 2009.

[2] S. M. Dance, B. M. Shield, Modeling of sound fields in enclosed spaces with absorbent room surfaces, Appl. Acoust. 58, 1–18, 1999.

[3] K. Jambrosic, M. Horvat, H. Domitrovic, Reverberation time measuring methods, Acoustics 08 Paris, 2008.

[4] http://www.maplesolution.com/sound_ab.php

[5] T. D. Rossing, Springer Handbook of Acoustics, Springer, 2007.

[6] F. Jacobsen, T. Poulsen, J. H. Rindel, A. C. Gade, M. Ohlrich, Fundamentals of Acoustics and Noise Control, Department of Electrical Engineering, Technical University of Denmark, 2009.

[7] L. L. Beranek, Concert Halls and Opera Houses: Music, Acoustics, and Architecture, Springer-Verlag New York Inc., 2004.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering

23rd National Conference &
4th International Conference
NOISE AND VIBRATION

Niš, 17 - 19. 10. 2012.

ANALYSIS OF THE PROBLEMS AND MISTAKES IN SCIENTIFIC PAPERS TITLES

Jelica Tošić[1]

[1] University of Nis, Faculty of Occupational Safety, Serbia, jelica.tosic@znrfak.ni.ac.rs

Abstract - *This paper set out to analyze the linguistic mistakes that appeared in the 2010 proceedings of the traditional Noise and Vibration conference (XXII conference). It is specifically concerned with the titles of the papers that were presented at the conference and published later on in the proceedings. Out of 36 papers, only one was published only in English and the equivalent title in Serbian was missing. Therefore 35 titles, all with both the English and Serbian versions, were subject of this analysis. Thus comparison of their meaning was possible. As none of the authors was from an English-speaking country, it was assumed that the English titles were actually the authors` translations from their native languages i.e. English was the target language. The mistakes that were identified were the subject of analysis and discussion in this paper.*

Key Words: *mistake, translation, proceedings, noise and vibration.*

1. INTRODUCTION

The aim of this paper is identification of the mistakes appearing in the papers` titles in the XXII Noise and Vibration conference proceedings. The problem that was recognized was the fact that the English used in the papers needed improvement. Scientists and professionals, who report on their findings at the conferences need not be perfect English speakers. What they write, however, when they want to communicate their results, should be written in a good language. This is important because they should not be misunderstood in the first place. It is also important because bad language can dispel readers from dealing with the texts. Both things are undesirable and can discourage the authors in their further work. That is why translation takes a crucial place in writing scientific and professional papers.

2. PROCESS OF TRANSLATION

Catford states that translation is `a process of substituting a text in one language for a text in another` (Catford 1965: 1). This is exactly what he begins his book *A Linguistic Theory of Translation* with. This is naturally a very simple answer to the subject emphasized in the title. Later on in his book, he clarifies the answer by introducing some new aspects of this seemingly simple process. Anyway, the two essential terms in translation process are mentioned in this definition: a source language (the one that the translation begins from) and a target language (the one that the translation is directed to).

One later definition of his is that translation is `the replacement of textual material in one language (SL) by equivalent textual material in another language (TL).` (Catford 1965: 20), adding that the key term in this definition is the term *equivalent*. As a matter of fact, translation is a good choice of the equivalents on the part of the translator. If he/she makes a wrong choice from the target language corpus, their translation is going to be faulty. Indeed, all the theorists of translation agree to that. Boris Hlebec, for example, cites Vladimir Ivir who states that the act of translation involves ` turning a message...previously expressed in one language into an equivalent value message expressed in another language` (Hlebec 1989: 6). Apart from the two previously mentioned elements of translation, this definition contains another element – a message. The message can be a very broad term – it can be a word, a phrase, a sentence, or some other larger unit of analysis. The point to be stressed here is the fact that whatever unit you look at, the equivalence between the source language and the target language must be observed.

The equivalence that these authors talk about could otherwise be formulated as meaning. Therefore what you want to achieve in translation is the equivalence of meanings in the target language compared to the meanings in the source language. This fact might look notorious but this is where the problems may arise, just as this is where the translator`s competence comes to the fore. In other words, the meaning is what is transferred. That is why `the unit of translation...is always as small as possible and as large as necessary` (Newmark 1982: 15). Although none of the defining adjectives in this definition *possible* and *necessary* is strictly defined, this is what is left to the translator`s disposal and this is exactly what makes the translation free, differentiating between various translators of the same text.

It goes without saying that the freedom is the function of some limitations. Newmark`s illustration of the process of translation is useful:

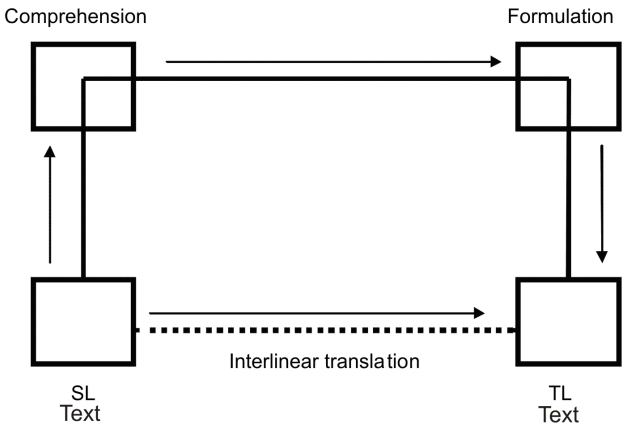


Figure 1. *The process of translation (Newmark 1982: 18)*

Simple as it is, it contains two important spots. One is that translation is impossible without understanding, and the other is that formulating the message is also very important. This makes the translator a mediator between the sender and the receiver of the message. He or she can offer the best possible solution to their readers or listeners. His or her aim, as has already been said, is free translation of the material. Literal translation is not the best achievement its fault lies in the fact that there `the process of translation has not been completed so that you can `sense` the presence of the original` (Jovanovic 2001: 31). (We can add that the translated text can suffer from the influence of the mother tongue, so that you can `sense` the presence of it too.) This can happen in all sorts of texts no matter whether they are meant for the general public or the competent professionals. Both general and technical texts should sound natural in the target language.

Some people believe that technical translation must be literal whereas literary translation must be free. Others disagree with this (Newmark 1982:5). The term *technical translation* refers to all the acknowledged fields of scientific and professional interest. The people reading this kind of texts are, however, for obvious reasons interested in having the text that is faithful to the original. All the scientific and professional progress depends on it. In order for the text to be usable to them, it has to be as literal as necessary, and as free as possible.

3. PROBLEMS AND MISTAKES IN TRANSLATION

Problems in translation can appear in all the parts of the communication chain. Mistakes are their natural outcome. They must be avoided and that is the reason why the process of translation should not be taken lightly. It is rather a serious job which involves full comprehension of the source text as well as the artful formulation in the target language. To reconcile these two processes it is necessary that the source language sense components be *redistributed* in the right way. This process therefore shows the translator where he or she can retain the word-for-word order, and where to opt for a free form, either in lexis or in grammar. This is a complicated process and it takes a lot of effort and competence.

On the other hand, if you look at the translated text, the analysis takes the form of the reverse process. The full competence in both the source and target languages is also necessary here. This enables the analyst to identify the mistakes first, and then to analyze and evaluate them. This paper is trying to do this. The final step of the mistakes classification will lead to the complete assessment of the material under observation. That will also lead to the improvement of the texts that should follow. Eventually it will lead to the avoidance of the future mistakes.

4. MISTAKES IN THE XXII NOISE AND VIBRATION CONFERENCE PROCEEDINGS

Noise and vibration is one of the scientific fields that deals with serious matters in terms of the working and living environment protection. It is a field in its own right. It is a separate field in that the experts deal with specific subjects and problems using the specific vocabulary or terms. If they want to use foreign sources of information (whatever form they might have, be it leaflets, instructions, smaller texts, or books), they have to deal with translations. What holds true for any translation is applicable to these translations as well. Namely, the translator must completely be familiar with both the source language and the target language. This makes more difficulties at one point of translation depending on who the translator is. If the translator is a linguist, he or she will have to make some additional effort and become familiar with the field of noise and vibration. On the other hand, the problem for the noise and vibration expert lies in becoming quite competent in the language he or she translates from or into. Only both of these conditions can make a good translator.

This paper set out to analyze the linguistic mistakes that appeared in the 2010 proceedings of the traditional Noise and Vibration conference (XXII conference). It is specifically concerned with the titles of the papers that were presented at the conference and published later on in the proceedings. Out of 36 papers, only one was published only in English and the equivalent title in Serbian was missing. Therefore 35 titles, all with both the English and Serbian versions, were subject of this analysis. Thus comparison of their meaning was possible. As none of the authors was from an English-speaking country, it was assumed that the English titles were actually the authors` translations from their native languages i.e. English was the target language. This was not the analysis of the terms pertinent to the field of noise and vibration. Upon analysis it was found that 24 titles had no mistakes. The following mistakes have been identified in the rest 11 titles:

1. Implementation of window acoustical parameters...

The underlined phrase consists of an adjective (*acoustical*) and two nouns. The order of the elements in English is similar to Serbian i.e. the adjective always precedes the noun to which it refers. *Acoustical* clearly refers to *parameters*. The third element in this phrase (*window*) is therefore displaced – the noun cannot precede the adjective although it is obvious that it is not this noun that is qualified by the adjective *acoustical*. Rather, the acoustical parameters belong to the window. Two things might have been done: either the noun *window* could have acquired the genitive form (*window`s*) in which way the belongingness is clarified, or the noun *window* could have been moved to follow the

adjective in which way the noun cluster is formed (*window parameters*). This formation is possible and frequent in English in both general and scientific writings. In this way the noun cluster follows the adjective and conforms to the rules of grammar.

2. Considerations upon the acoustic field...

The awkward choice of the initial noun and the following preposition in the title has been improved in the abstract with *investigation of*.

3. ...in the area of Belgrade building a new bridge over the river Sava

The noun *Belgrade* is used here as an adjective. As an adjective it has to precede the noun to which it refers. In this case it is *bridge* so that the words *Belgrade bridge* fit together. The paper is actually talking about one of the Belgrade bridges, and not about Belgrade building as a process. The adjective should therefore be moved from its present position.

4. Impact of the planned E-75 highway to the noise level...

The noun *impact* denoting the effect or influence produced by a highway in this case should be followed by the preposition *on* denoting the objects or processes that are influenced.

5. ...Džordža Vašingtona Str.

One of the problems in translation is the treatment of personal nouns or names. Two things could be noticed in this title, first that the name *Podgorica* is retained (not translated) and then that its form is unchanged (without any inflection). This conforms to the English rule whereas Serbian is a highly inflectional language. The negative transfer is visible in this title in the translation of another name *Džordža Vašingtona Str.* This toponym originates from English and when returning to it in translation it should logically acquire its original form. All the more so that the designation *Str*. is meant to make the reference clear. It was however misspelled – the shortened form of *Street* is *St*.

6. Fault identification in roller bearings by the means of vibration...

The phrase *by means of* (without the article) means *by using* or *with the aid of*.

7. Vehicle transmission gear vibration analysis case

Comparing the English with the Serbian title of this paper. one can see that the latter title contains a preposition which is missing in the English version. This is of course not a mistake. Being uninflectional the English language allows recombining the nouns so that the sense transmitted by inflections is not lost. This recombination can be applied to two or more nouns – the more nouns are recombined, the more difficult it is to understand the whole. In this case, there are six nouns in the title and no preposition. If there were the prepositions (which is also a possible variant), some potential difficulties would be avoided. Anyway, the existing variant is also understandable. As a matter of fact, the title could be divided into two wholes *vehicle transmission gear* and *vibration analysis case*. This is obvious in the title in Serbian – the wholes are divided by the preposition. Although the dictionaries say that the meaning of the nouns *gear* and *transmission* is, more or less, the same, so that one of them seems superfluous, the existing phrase would sound more logical if the nouns *transmission* and *gear* changed their places.

8. Acoustic vehicles development

Acoustic is an adjective that grammatically can refer both to *vehicles* and *development*. Its position here gives the wrong meaning to the whole. What is needed here is the noun *acoustics*. Thus the title consists of three nouns which are not distributed in the right way. *Acoustics* should follow *vehicles*. Although the title is wrong, the phrase used in the abstract of the same paper, however, is right: *vehicle acoustics*.

9. Appendix for...

There is the wrong choice of the word here. *Appendix* is some material at the end of a book containing additional information. The authors certainly meant *contribution*. They actually used the latter term in their English abstract although the title, which is more striking, remained unchanged.

10. and 11. ...measuring of asynchronous motor

What the authors of this paper measured were the vibrations and not the motors. Contrary to that, the title suggests the opposite. This is the trap that Livija Cvjeticanin avoided by using the preposition *in*. And this is the trap that a group of authors from thr Electronics Faculty did not avoid. (determination of electromechanical model).

The previous analysis leaves us with the following results:

Table 1. *Type and Number of Mistakes*

Mistake	Incidence
Preposition	4
Noun Cluster	3
Word Choice	3
Position of the Adjective	1
Abbreviation	1
Article	1

The table shows an interesting fact: the use of the English prepositions is a greater problem for foreigners whereas the noun clusters present fewer difficulties. This might result from a purely psychological reason: people pay more attention to complicated items and therefore learn them. Prepositions do not seem to make the meaning different in most cases and therefore are frequently not given due consideration.

CONCLUSION

When a scientific conference is over, the only thing that is left to remind the participants, other scientists, and the public of the achievements presented at the conference is the conference proceedings. It is an important document that is illustrative of the knowledge that has been acquired at the conference and it can serve as a source of information and comparison for some future presentations and papers. It is

therefore very important that it be written in a good language. Written (printed) texts cannot be deleted, they are permanent. That is why all the possible mistakes should be avoided. Speech, on the other hand, is less formal and mistakes are likely to be tolerated. What was allowed at the conference is not allowable in the proceedings. Two things could be suggested as a solution: first, the authors should consult linguists for revision and correction, and second, the proceedings editors should review the submitted papers not only for the content but also for linguistic correctness.

REFERENCES

[1] Catford, J.C. (1965): *A Linguistic Theory of Translation* (Oxford: Oxford University Press)

[2] Hlebec, Boris (1989): *Opšta načela prevodjenja* (Beograd: Naučna knjiga)

[3] James, Carl (1998): *Errors in Language Learning and Use* (Harlow: Pearson Education)

[4] Jovanović, Mladen (2001*): O prevodjenju* (Beograd: Udruženje naučnih i stručnih prevodilaca Srbije)

[5] Newmark, Peter (1982): *Approaches to Translation* (Oxford: Pergamon Press)

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

EXAMINING AUDITORY PERCEPTION AND AUDITORY MEMORY BY APPLICATION OF PHS AND ELECTROPHYSIOLOGICAL RESEARCHES

Mirjana Sovilj[1], Ljiljana Dobrijevic[2]

[1, 2] Institute for Experimental Phonetics and Speech Pathology “Djordje Kostic”
Life Activities Advancement Centre-innovation centre, iefpgmir@gmail.com

Abstract – *Auditory perception and memory, and thereby learning potential, develop in the prenatal period. The experiments carried out at the Institute indicated that from the 28th GW (gestation week), the prenatal child responds to a defined sound stimulus, stimulus, which resulted in the first method of Prenatal Hearing Screening (Sovilj-Ljubic). The paper also present results of electrophysiological researches of the child in the prenatal period and the third month after birth in different tasks, which offers a significant insight into functioning of hearing and memory, and the role of sound in the development of a human being.*

Key words: *prenatal child, fetus, memory, EEG, prenatal hearing screening, prenatal development.*

1. INTRODUCTION

Researches carried out over a number of decades indicate that the prenatal child is capable of perceiving certain stimuli, memorize them and learn. Privilege of a man - homo loquens - to communicate by speech relies on the initial improvement of hearing. Cell division in the prenatal development, from the period of conception to cell differentiation and migration in the process of organism formation, is under the influence of sound-vibration. Basis of matter preservation is sound-vibration. That is why hearing represents one of the most important functions of human organism.

Tomatis claimed that “90% of energy which the brain needs is stimulated via hearing. The brain was developed from the organ of hearing and owing to the EAR, over millions of years, it became more refined and complicated in its structure.“ [1].

Although a concentric series of barriers “protect” the fetus from the outer world - amniotic fluid, fetal membrane, uterus and the mother's abdomen - it lives in the womb constantly stimulated by sounds, vibrations and movements. Many studies confirm that abundance of sounds reach the uterus despite the background noises generated by the mother's organism and the placenta. Speech intonational frequency, intensity and rhythm, as well as music, reach the fetus without significant distortions. Compared to the outer sounds, the mother's voice has a more profound influence because it is transferred from her own body to the prenatal child and represents the spiritus movens of one's personality.

Sounds have a surprising effect on the heart rate of the prenatal child - e.g. a five-second stimulus can cause changes in the heart rate and movements which last even longer than an hour. Some music sounds can even cause changes in metabolism.

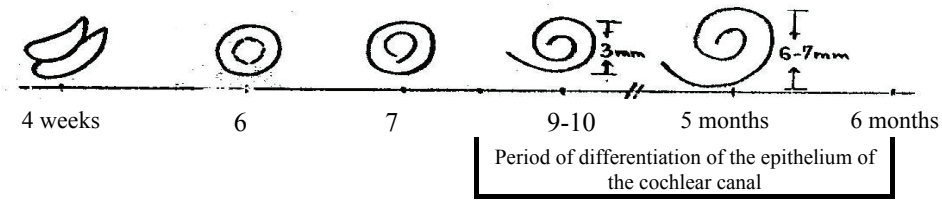
Ultrasound examination of 400 fetuses, with pure sound amplified at 250-500 Hz indicated that reactions appeared in the 16th GW [12]. This is particularly significant because reflex hearing appears eight weeks before the ear is completely structured, about the 24th GW. The significance of hearing for a person's development lies in the fact that the inner ear is completely formed already in the 5th month of the prenatal developement.

These findings indicate the complexity of hearing, which begins with the skin and the skeletal network, the skin being a multireceptive organ which integrates input vibrations, thermal receptors and pain receptors. Enhanced by vestibular and cochlear information, this primal hearing system starts functioning about 24 weeks before birth.

2. DEVELOPMENT OF HEARING AND PROGRAMMING OF THE PRENATAL CHILD

Researches indicated that morphogenesis of the auditory analyzer begins at a very early development phase of the prenatal child (Picture 1). The cochlea reaches the size of 6-7 mm (as in an adult) in the 5th month of the prenatal development. Differentiation of the epithelium which covers the cochlear canal begins in the 8th GW and ends in the 6th month of prenatal development. Development of different parts of the Organ of Corti begins from basal parts towards the apex. Both domestic and foreign researches proved that reflex listening is established in the 16th (GW), and reliable response to sound stimulus from the outer surrounding is registered between the 26th- 27th GW [2].

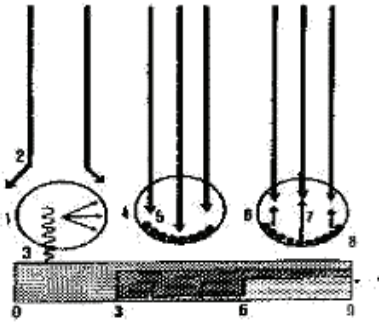
We will analyze the way the prenatal child reacts to outer sound stimuli and how “programming” the child is carried on, having in mind Milakovic’s scheme of the initial stage of creating the child’s personality in the prenatal period. [3]. The starting point was Sontag’s theory that the child is a part of the mother’s psychosoma, who transfers the states she is in via “blood excitations“ i.e. she transmits her experiences to the child. Milakovic made a step further and in the possibility of transferring the mother’s experience he noted the process of “fetus programming”. It is via “blood excitation“ that the mother teaches the prenatal child about everyday oscillations and models of frustration and satiation, which will be the content of its life after birth. Communication mother-child in the prenatal period, both mental and verbal, is of the utmost importance for children’s development, whereas the mother’s voice is the “pillar“ of the child’s personality. [4].



Picture 1 *Morphogenesis of auditory analyzer*

The simplified explanation would be that learning takes place on the metabolic level, because the areas of CNS in charge of metabolic and vegetative control are fully developed, such as the mesodiencephalon where integration centres of soma-psyche relation are situated.

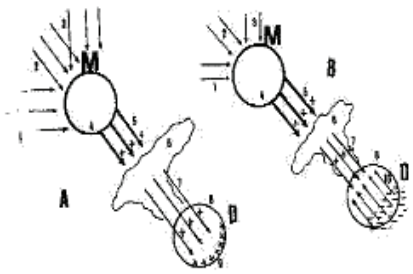
Via mechanisms structured in such a way, the prenatal child and the mother communicate via the placenta and information is transferred from the mother's mesodiencephalon to the child's mesodiencephalon in a few seconds, following the principle of a transmitter (mother) and a receiver (child). Programming of the child according to the simplified Milakovic's scheme has the following stages (Picture 2):



Picture 2 *Programming of the child according to the simplified Milakovic's scheme*

1) In the first trimester of pregnancy, hereditary factors have a dominant role and the mother's messages do not penetrate into neurophysiological structure of the fetus. This formulation is no longer acceptable. Namely, it is certain that "communication" mother-child is present already in this period, although heredity is predominant.
2) In the second trimester, the mother's messages penetrate and program the child's structures by their rhythms.
3) In the third trimester, the child "can" refuse mother's messages and fight against outer unpleasant influences, thus fighting for its own homeostasis.

Picture 3 shows a simplified scheme (A) of the information flow from the mother into the child's organism. 1, 2 and 3 are stimuli which reach the mother's mesodiencephalon (4) from her senses, inner sensors and memory.



Picture 3 *Mother-child information flow*

Via reactions of the mesodiencephalon, the mother's state is reflected on the composition of blood which circulates towards the placenta (5). Via the placenta (6), composition of the mother's blood is taken over by the child's blood (7) and then, via umbilical cord it enters its bloodstream and reaches the child's mesodiencephalon (8). Received information from the mother's blood is memorized as a program in the child's mesodiencephalon and other centres and is completely identical to the mother's. This level of programming lasts from 0 to 6 months. Scheme B shows the period during which the child creates its own program with the aim of preserving homeostasis. Via auto control (10) it reacts to any influence which disturbs its homeostasis. Thus, the child will react to the mother's "messages" of thirst by drinking the amniotic fluid, to her increased blood sugar it will react by the increased secretion of insulin, in situations of distress by sucking its thumb etc. In this period, it practices the functions which are primary in preserving life immediately after birth. Communication mother-child is intensive and it can be physically detected by intensifying or reducing the child's movements while verbally addressing the child, stroking the abdomen, listening to music etc. This process of programming is realized within 6 to 9 months.

This simplified presentation of the programming process of the prenatal child shows that it consists of genetically modulated development, as well as the child's ability to adapt. The child carries one part of instinctive knowledge as heritage, whereas it has to learn the other part during the prenatal period in order to develop adaptation mechanisms which will provide "survival" during and after birth.

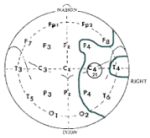
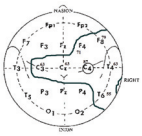
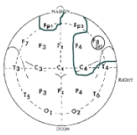
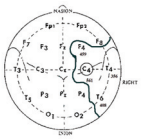
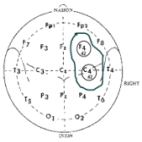
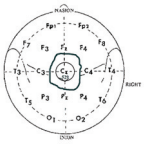
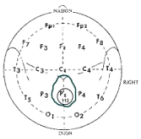
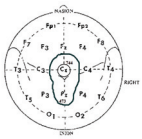
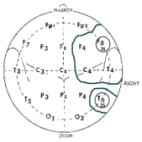
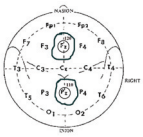
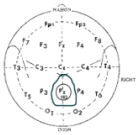
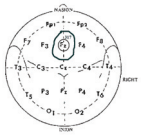
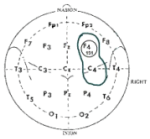
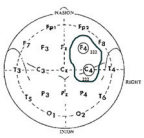
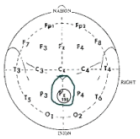
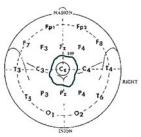
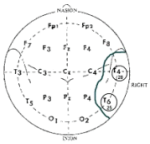
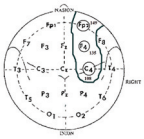
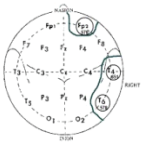
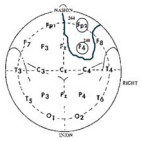
Large and frequent oscillations in the mother's emotional behaviour influence the change of rhythms in the fetus, causing disharmonious, repetitive, arrhythmic discontinuity in its acoustic-vibratory surrounding.

This form of communication is carried out through the communication below the consciousness threshold, which is known as an emphatic connection or transpersonal communication between the mother and the prenatal child. By adequately educating the mother, this communication can be developed into a complete, conscious communication with the child in the prenatal period. [5], [6], [7].

In our researches [8], [9], [10] over the previous years, we examined reactions of the prenatal child to a stimulation in the form of a story read by the mother during the 8th month of pregnancy, when the same story was read by unknown female and male voices, and when an English translation of the story was read by the mother and by an unknown female voice and these reactions were compared with reactions to the rustle of water and the murmur of people. Analyses of CTG recording indicated that the prenatal child reacts identically (there are no significant changes of the heart frequency) when it is stimulated by the rustle of water, the murmur of people and by reading of an English translation of a story, regardless of whether it was read by the mother or a stranger.

Significant increase of the heart rhythm frequency appeared when the mother read a story in the native language. When a story was read in the native language by unknown male or female voices, we noted differences in the reaction to these two readers, but the heart frequency was significantly lower in both cases compared to the period when the same story was read by the mother.

The whole experiment was repeated at the beginning of the second month (after birth the newborn was not stimulated by this story), and the newborn's reactions were monitored by quantitative EEG (map) recording. Again, it was unmistakably established that during the stimulation by the rustle of water, the murmur of people and reading of the same English translation of the story, the same cerebral regions were activated, whereas completely different regions were activated when the story, by which the child was prenatally stimulated, was read by the mother. There is also a difference in the activation of cerebral zones between unknown male and unknown female readers. In this experiment, all readers also read an unfamiliar text (the child heard the text for the first time). Results indicated that the unfamiliar text activated new cerebral zones in the newborn in response to all three readers, compared to a familiar story in the native language and in English. Zones which were activated during the stimulation by the murmur of people, the rustle of water and reading of an English translation of the story were identical and very similar to the zones activated at the state of rest (without stimulation).

	Theta rhythm		**Delta rhythm**	
Stimulation	**AGE: 24 DAYS**	**AGE: 75 DAYS**	**AGE: 24 DAYS**	**AGE: 75 DAYS**
No stimulation at rest	 1	 2	 3	 4
Mother – familiar text	 5	 6	 7	 8
Mother – unfamiliar text	 9	 10	 11	 12
Unknown speaker-familiar text	 13	 14	 15	 16
Unknown speaker-familiar text in a translation	 17	 18	 19	 20

Picture 4 *Theta and delta cerebral rhythms 24 and 7 days after birth*

Experiment during the prenatal period indicates that the prenatal child possesses auditory ability, memory and learning ability, which enable differentiation between familiar and unfamiliar voices, as well as between male and female voices, but at the same time differentiation between the native language and a foreign language and familiar and unfamiliar texts.

1) The situation at the state of rest, as well as interpretation of the familiar text translated into English are processed in the theta and the delta rhythms in the right hemisphere and unihemispherically in both observed ages (Pictures 4.1-4.4 and Pictures 4.17-4.20).
2) At the age of 24 days, in all three situations in the native language and the familiar text, the theta rhythm is processed in the right hemisphere and the delta rhythm is processed symmetrically and bihemispherically (Pictures 4.5, 4.9, 4.13).
3) At the age of 24 days, the mother's voice and the familiar text are processed in the theta rhythm in the similar way (Pictures 4.5, 4.13) with respect to the processing region (fronto-central region), and with bicentric presentation F4 and C4. In the situation of an unknown voice (Picture 4.13) processing is unicentric with the executive system in F4.
4) At the age of 24 days, an unfamiliar text in the native language and the mother's voice are processed in the theta rhythm in the wide area of the right hemisphere, bicentrically in two independent centres in F8 and T6 (Picture 4.9).
5) At the age of 24 days, in the situation of a known and an unknown speaker, the delta rhythm is processed unicentrically and bihemispherically, in the central region and parietally (Pictures 4.7, 4.11, 4.15).
6) At the age of 75 days, in the stimulation with a known voice in the native language (Pictures 4.6, 4.8), as well as in the stimulation with an unfamiliar text (Pictures 4.10, 4.12), processing in both rhythms is realized bihemispherically in central regions, but they differ with respect to location and the number of executive centres. During the stimulation with an unfamiliar text, text processing is realized in the theta rhythm, bicentrically and bihemispherically (frontal and parietal) and in the delta rhythm bihemispherically and unicentrically in the frontal region.
7) At the age of 75 days, in the stimulation by an unknown voice (Picture 4.14) the theta rhythm is processed bicentrically in the right hemisphere (F4-C4), which is similar to the processing of the theta rhythm, at the age of 24 days, with bihemispherical central presentation and the delta rhythm in unicentric presentation.
8) In the situation with an unknown speaker and an unfamiliar language (English translation of the text) at the age of 24 days, the theta and the delta rhythms are processed in the right hemisphere at the same location bicentrically, but the deltarhythm is also processed in the frontal region unicentrically (Pictures 4.17, 4.19).

In the same situation, at the age of 75 days, the theta and the delta rhythms are processed unilaterally, the theta rhythm being located fronto-centrally with three executive centres, and the delta rhythm frontally with two executive centres.

At the same time, these researches contradicted the researches which stated that prenatally memorized contents are retained up to 21 days after birth [11], [12], [13], [14], since prenatal memory is capable of retaining information longer than 75 days after birth.

Our researches, as well as researches of authors worldwide indicated the necessity of examining the state of hearing in the prenatal period. Our researches over many years resulted in the development of the method for examining auditory perception in the prenatal period, first of that kind in the world

3. PRENATAL HEARING SCREENING (PHS)

PHS was developed at the IEPSP and is performed by Sovilj-Ljubic method [2] as a standard ultrasound examination with amplification of a defined sound of 1500-4500 Hz frequency range, 90 dB intensity and 0.2 sec. duration. It is based on the measurement of changes of cerebral cortical circulation in the a.cerebri media (ACM). Changes of Pi (pulsatile index) values before and after the auditory stimulus (AS) indicate the change in the blood flow in the ACM. If Pi values are lower after AS, they indicate an increased blood flow in the ACM, and if its values are higher compared to a basic Pi, then the blood flow is decreased. This established two directions of psychophysiological reactability (DPR) – positive and negative. In the previous researches about 25% of prenatal children population reacted with the positive DPR, and about 75% with the negative DPR, indicating that PHS in the prenatal period can also detect basic type of the child's personality. The positive DPR indicates decreased flow in the ACM – "retreat", and negative to its increase - "action". Obtained percentage of the DPR completely coincides with the data from the literature regarding the percentage of extrovert and introvert persons in the world population, i.e. 75% of extrovert and 25% of introvert. This was also confirmed by our researches of psychophysiological development and behaviour of the children population at the age of 3, in which PHS was applied before birth.

PHS can be reliably applied from the 27 GW (gestation weeks) until birth.

PHS is within normal limits if PHS value is up to 14.6 - higher values indicate the presence of risk-factors for development of hearing as well as verbal communication after birth.

Increased PHS values indicate that it is necessary to apply the early Prenatal Audio Linguistic Treatment (PALT) of the prenatal child. Our previous researches indicated that the PHS should be applied to the whole population of prenatal children, since about 30% of prenatal children from normal pregnancies have increased PHS values.

Application of the PHS and the PALT represents the most contemporary, efficient and cheap form of the prevention of hearing and speech disorders, as well as the prevention of far-reaching consequences of behaviour and learning disorders in children population.

4. EFFECTS OF PRENATAL AUDITORY STIMULATION

Studies of learning abilities in the prenatal period are based on the comparison of the group of prenatal children who were exposed to the rich prenatal stimulation and the group which was not included in the stimulation [15]. Postnatal development of both groups was examined by standard

development tests, which indicated significant contribution of sensory stimulation in the sphere of motor performances, visual skills, emotional reaction and verbal communication. Even more impressive is the fact that when these prenatal effects are consolidated with postnatal reactions, the group which was prenatally stimulated has the advantage. Table 1 shows the results of the success of the stimulated group in the areas of language development, memory, social intelligence and reasoning at the age of 3.

Table 1 *Advantages of prenatally stimulated children*

Language	Memory	Social intelligence	Reasoning
38%	47%	51%	82%

The results of children tested in the third year of life indicate a significant advantage in the development of prenatally stimulated children. Expressed as percentage, the results clearly point to the advantages of the experimental group, not only in the results given - these children also have better weight at birth, faster sensorimotor development, they begin to talk earlier etc.

ACKNOWLEDGEMENTS

This paper is part of the Project OI 178027-"Interdisciplinary researches of the quality of verbal communication", financed by the Ministry of Education and Science of the Republic of Serbia.

REFERENCES

[1] A. A. Tomatis: "Ontogenesis of the faculty of listening" T. R.Verni (Ed.): Pre-and Perinatal Psychology, Human Sciences Pres, 1987.

[2] M. Sovilj, A. Ljubic, V. Milenkovic, S. Djokovic: "Possibilities of prenatal researches of reaction to sound in fetus with congenital infections, Collection of abridged works, X Jubilee Symposium – Section for perinatal medicine. S.L.D.,1992, Belgrade, pps 17-18

[3] I. Milakovic: "When mother and her child were alone, Svijetlost Sarajevo, ZUNS, 1968, Belgrade.

[4] M. Sovilj, S. Djokovic: "Development of crying-cry of a newborn from birth to the end of the first month", Defectology in theory and practice, Belgrade1994, pps 194-200.

[5] M. Sovilj, Lj. Jelicic, M. Vujovic, I. Barlov: "Development of senses and fetal behaviour and researches on auditory perception and prenatal auditory stimulation", chapter in the monograph: S. Jovicic, M. Sovilj (editors): Speech and Language: Interdisciplinary Researches on Serbian Language, I, IEPSP, 2004, Belgrade.

[6] M. Sovilj: "Sound, hearing and consciousness, downward processes in the perception representation mechanisms", Napoly, 1998, pp. 487-493.

[7] T. Adamovic, M. Sovilj, M. Subotic: "Prenatal Memory and Learning", S. Jovicic, M. Sovilj (editors):Speech and Language: Interdisciplinary Researches on Serbian Language, I, IEPSP, 2004, Belgrade

[8] Z. Radicevic, M. Vujovic, Lj. Jelicic, M. Sovilj: "Comparative findings of speech and language processing at an early ontogenetic age in quantitative EEG mapping". Experimental Brain Research, 2008.

[9] Z. Radicevic, M. Sovilj, Lj. Jelicic, M. Vujovic: "Mapping of power and concentartion of infant´s brain electric activity in examining speech-language stimulation", The 10th International Biofeedback Conference, 2006, Vienna, Austria.

[10] Z. Radicevic, M. Sovilj, Lj. Jelicic, M. Vujovic: "The mapping of theta and delta brain electric activity strength in infant during conditions of speech and language stimulation". NHS Conference "Beyond Newborn Hearing Screening: Infant and Childhood Hearing in Science and Practice", 2006, Cernobbio, Italy.

[11] D. S. Richards, B. Frentzen, K. J. Gerhardt, M. E. McCann, R. M. Abrams: "Sound levels in the human uterus. *Obstetrics & Gynecology*, 1982, 80, pps 186-190.

[12] S. Shahdullah, P. G. Hepper: "Frequency discrimination by the foetus. *Early Human Devel*, 1994, 36, 13-26.

[13] H. F. R. Prechtl: In Nijhuis JG (Ed.), *Fetal behaviour*. Development and perinatal aspects. United Kingdom, Oxford University Press, 1992.

[14] H. Haynes, B. L. White, R. Held: "Visual accommodation in human infants. *Science*, 1965, pps 148, 528-530.

[15] Lj. Jelicic: "Psychophysiological characteristics of development in children with prenatally examined reaction to sound stimulus", 2009, Doctoral dissertation, CMS University, Belgrade.



University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

PERCEPTION OF AND ATTITUDES TO URBAN NOISE AMONG CITIZENS OF NIS (SERBIA)

Ljiljana Stosic[1], Ljiljana Blagojevic[2], Suzana Milutinovic[1]

[1]*Institute of Public Health, Nis, Serbia, ljstosic@live.com*
[2]*University of Nis, Faculty of Occupational Safety, Serbia*

Abstract - *Urban noise has become dominant negative environmental factor for city populations. The aim of this paper was to indicate the significance of urban noise monitoring and to assess knowledge and attitudes of citizens in Nis (Serbia) about this environment problem. A cross-sectional study was performed on 911 adults residents with 388 males (42.6%) and 523 females (57.4 %). Based on the results of noise measurements the exposed group comprised individuals living in a noisy area (daily period Leq ≥55dBA and night Leq ≥45dBA), while the control group comprised individuals living in a quiet area (daily period Leq ≤ 55dBA and night Leq ≤ 45dBA). The residents were interviewed about knowledge and attitude towards various environmental factors including noise. Noise annoyance was estimated using verbal annoyance scale. The study showed that 21.20% of the citizens from the noisy area ranked noise as the most important risk factor while this percentage in quiet streets was 2.5% ($\chi 2=192.32$; $p<0.001$). Road traffic was the most important source of noise for both groups. The subjects from noisy streets were more frequently highly annoyed in comparison with the residents from quiet streets ($\chi 2=150.25$; $p<0.001$). A substantial inter-individual variance of health effects of noise was found. A factor that might explain a part of this variance might be attitude towards noise which in turn is influenced by place of residence.*

1. INTRODUCTION

During the last 20 years there has been increasing concern about the quality of the environment. Along with air and water contaminants, noise has been recognized as a serious pollutant. Urban noise, a major environmental noxious factor is defined as noise emitted from all sources, excluding industrial (workplace) noise exposure. Main sources of community noise include road, rail and air traffic, industries, construction and public work, and the neighbourhood. In the European Union, about 40% of the population is exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dBA daytime; and 20% is exposed to levels exceeding 65 dBA (Berglund et al.,1999).

Long term noise exposure is associated with a number of effects on health and well-being. These include annoyance, sleep disturbance, disturbance of daily activities, and physiological responses such as hearing loss, hypertension, and ischaemic heart disease (WHO,1999).

The aim of this paper was to indicate the significance of urban noise monitoring and to assess knowledge and attitudes of citizens in Nis (Serbia) about this environment problem.

2. SUBJECTS AND METHODS

2.1 Measuring of noise

Measuring of traffic noise in the city of Nis was performed on six measuring sites in Nis, in accordance with the Serbian and ISO Noise Regulations (ISO, 1982) with a Noise Level Analyzer Type 4426 (Brüel & Kjær). The total number of samples was 9000, with a period of sampling 0.1 s in „fast“ dynamic range, during three day periods (09.00-12.00, 13.00-16.00, 17.00-20.00,) and in two night periods (22.00-01.00, 02.00-05.00). The measurements were done from May 2007 to April 2008. Based on the results of noise measurements the streets where the subjects had residence were regarded noisy (daily period Leq ≥55dBA and night Leq ≥45dBA) or quiet (daily period Leq ≤ 55dBA and night Leq ≤ 45dBA).

2.2 Study sample

Based on the earlier measurments and traffic density, a total of 3000 questionnaires were distributed to all apartment residents through their mail boxes in three noisy streets of a central area of Nis and three streets in a control quiet zone. The number of distributed questionnaires was equal to the number of adult dwellers in each apartment. The residents were asked to fill in the questionnaires by the next day, when these were collected. To be enrolled in the study, the residents had to live at the present address for longer than 1 year.

The response rate was 35.4% with 1063 filled questionnaires. After excluding subjects whose period of residence was shorter than 1 year, the final sample consisted of 911 residents, 388 (42.6%) males and 523 (57.4%) females.

2.3 Questionnaire

The questionnaire was anonymous and consisted of several segments. The first part included general socio-demographic data: age, sex, apartment size, education, period of residence and daily time spent in the apartment.

The residents were interviewed about attitudes towards various environmental factors such as air pollution, noise, waste, water pollution, radiation. They were asked to rate environmental factors by their hazardous effects and to point out the most important sources of noise in their environment. They were to assign numbers 1 to 5 to environmental factors where number 1 was the most important and 5 was the least important factor. Noise annoyance was estimated using verbal annoyance scale (0-4: graded „not at all“, „little“, „moderate“, „rather“ and „extremely“).

2.4 Statistical analysis

Interview data were analysed using SPSS (version 10.0) and Statcalc from EPI-INFO (version 6) statistical computer programs. Statistical significance of difference was established by Pearson Chi–Squared test for comparison of means of numeric variables with normal distribution in two independent samples. Mann-Whitney U test was used for compare the means of ranks and numeric variables with asymmetric distribution in two independent samples. A probability of mistake less than 5% ($p<0.05$) we accepted as significant.

3. RESULTS

The results of noise measurements (Table 1) showed that the average daily and night Leq were significantly higher in noisy streets compared to quiet ones (61.33±2.31 : 43±3.46; z=2.02; p=0.043).

Comparison of sociodemographic data between the groups showed that the residents of noisy streets were 4 years older on the average. They also had higher density of housing (less m^2/person) and lower number of people with elementary school education, compared to the subjects from quiet streets (Table 2).

Table 1 *Results of noise measurements*

Zone	Streets	Day Leq (dBA)	Average number of light vehicles at day time per hour	Average number of heavy vehicles at day time per hour	Night Leq (dBA)	Average number of light vehicles at night time per hour	Average number of heavy vehicles at night time per hour
Noisy	Avenue Nemanjica	63	576	44	60	292	8
	Avenue Dr Zorana Djindjica	67	940	62	60	368	2
	Vozdova street	68	955	46	64	395	10
Quiet	Somborska street	51	44	8	45	21	1
	Niska spa-center	47	35	8	39	16	0
	Niska spa	51	32	4	45	8	0

Table 2 *Basic sociodemographic data of the subjects*

Variable	Noisy Streets (N=463)	Quiet streets (N=448)	p
Age	45.00 ± 16.32	41.71 ± 13.64	0.008**
Males Females	204 (44.10%) 259 (55.90%)	184 (41.10%) 264 (58.90%)	0.36*
Apartment size (m^2/person)	63.28 ± 18.31	77.67 ± 30.18	<0.001**
Period of residence (years)	17.89 ± 13.03	17.92 ± 11.64	0.72**
Time spent daily in the apartment (hours)	14.45 ± 3.44	14.18 ± 3.11	0.33**
Education (%) -Elementary -Secondary -College	 1.9 59.8 38.2	 4.9 58.3 26.8	0.03*

*Pearson χ^2- test; **Mann-Whitney U-test

The study showed that the respondents from noisy streets ranked noise as the most important risk factor in 21.20% of the responses, while the same rate in quiet streets was 2.5%. Residents of noisy area ranked noise as least important in 13.0%, and in the quiet area, 41.1 % ($\chi 2=192.32$; $p<0.001$) (Table 3).

Regarding the most important sources of noise, it was found that road traffic and works on the street were the most important ones for both groups. Least important sources were industry, neighbourhood noise and installation in buildings (Table 4). Statistically significant differences were found for industry, neighbourhood noise and installation in buildings.

Table 3 *Rank of importance of different environmental factors, assigned by residents in noisy and quiet streets*

Rank of importance	Environmental factors									
	Air pollution		Waste		Noise		Water pollution		Radiation	
	Noisy	Quiet	Noisy	Quiet	Noisy	Quiet	Noisy	Quiet	Noisy	Quiet
1	147 (31.7%)	144 (32.1%)	52 (11.2%)	75 (16.7%)	98 (21.2%)	11 (2.5%)	74 (16.0%)	83 (18.5%)	92 (19.9%)	135 (30.1%)
2	141 (30.5%)	106 (23.7%)	71 (15.3%)	108 (24.1%)	128 (27.6%)	44 (9.8%)	100 (21.6%)	149 (33.3%)	26 (5.6%)	42 (9.4%)
3	96 (20.7%)	120 (26.8%)	158 (34.1%)	139 (31.0%)	107 (23.1%)	83 (18.5%)	74 (16.0%)	69 (15.4%)	27 (5.8%)	38 (8.5%)
4	48 (10.4%)	59 (13.2%)	127 (27.4%)	89 (19.9%)	70 (15.1%)	126 (28.1%)	169 (36.5%)	111 (24.8%)	48 (10.4%)	62 (13.8%)
5	31 (6.7%)	19 (4.2%)	55 (11.9%)	37 (8.3%)	60 (13.0%)	184 (41.1%)	46 (9.9%)	36 (8.0%)	270 (58.3%)	171 (38.2%)
	χ^2=11.42 p=0.02		χ^2=22.99 p<0.001		χ^2=192.32 p<0.001		χ^2=23.33 p<0.001		χ^2=37.54 p<0.001	

Table 4 *Rank by importance of the different sources of noise*

Rank	Source of noise									
	Road traffic		Works on the street		Industry		Neighbourhood noise		Installation in the building	
	Noisy	Quiet	Noisy	Quiet	Noisy	Quiet	Noisy	Quiet	Noisy	Quiet
1	191 (41.3%)	170 (38.0%)	106 (22.9%)	108 (24.2%)	54 (11.7%)	69 (15.4%)	75 (16.3%)	79 (17.6%)	37 (8.0%)	22 (4.9%)
2	91 (19.7%)	104 (23.3%)	178 (38.4%)	181 (40.5%)	66 (14.3%)	64 (14.3%)	68 (14.8%)	75 (16.7%)	59 (12.7%)	25 (5.6%)
3	104 (22.5%)	118 (26.4%)	71 (15.3%)	77 (17.2%)	100 (21.6%)	137 (30.6%)	109 (23.7%)	87 (19.4%)	78 (16.8%)	27 (6.0%)
4	45 (9.7%)	36 (8.1%)	80 (17.3%)	63 (14.1%)	92 (19.9%)	106 (23.7%)	121 (26.4%)	138 (30.8%)	125 (27.0%)	104 (23.2%)
5	32 (6.9%)	19 (4.3%)	28 (6.0%)	18 (4.0%)	151 (32.6%)	72 (16.1%)	86 (18.7%)	69 (15.4%)	164 (35.4%)	270 (60.3%)
	χ^2=7.01 p=0.14		χ^2=4.20 p=0.38		χ^2=36.38 p<0.001		χ^2=23.33 p<0.001		χ^2=69.93 p<0.001	

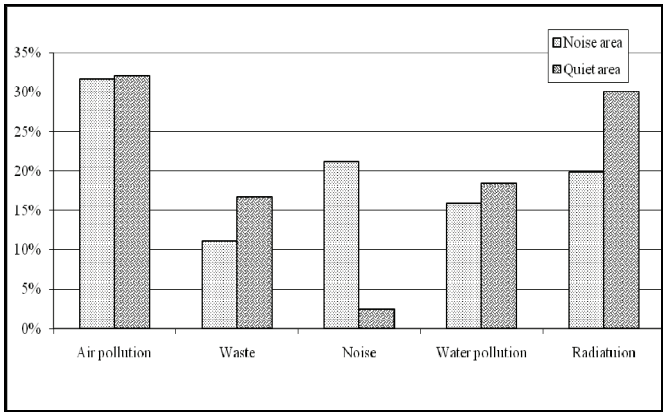


Figure 1 *Percentage of environmental factors ranked first by importance*

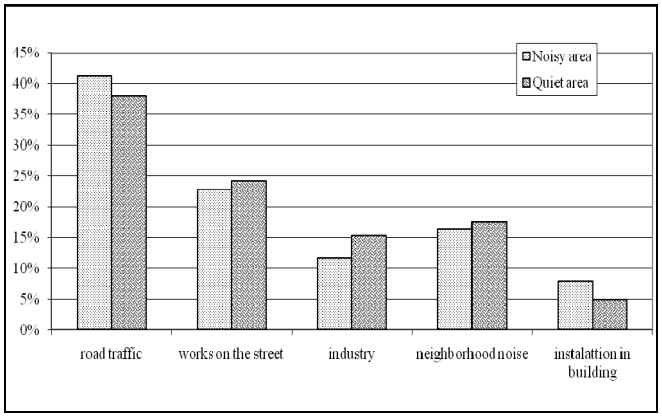


Figure 2 *Rank by importance of the different sources of noise*

The distribution of residents in relation to degree of noise annoyance showed that the subjects from noisy streets were more frequently highly annoyed in comparison with the residents from quiet streets (χ^2=150.25; p<0.001) (Figure 3).

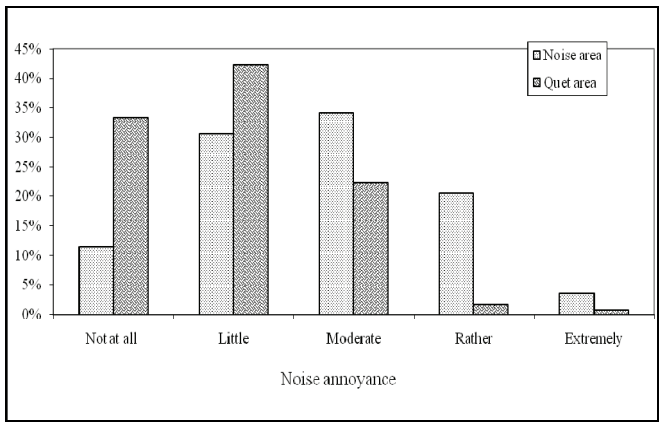


Figure 3 *Distribution of noise annoyance degrees among the residents from noisy and quiet streets (for annoyance grades, see Methods)*

4. DISCUSSION

Environmental noise is an important ambient stressor. Unlike other physical ambient factors (i.e. electromagnetic fields or air pollutants), noise is perceived by a specific sensory system (auditory system) in humans. It is therefore a phenomenon that is sensed and evaluated by everybody, and this way exposure to noise is one of the most frequent complaints of populations living in large cities.

The combination of noise with other acute environmental, social or psychological stressors impairs an individual's adaptation capacities, increases his/her vulnerability to stressors, and increases the chance of occurrence of adverse health effects (Wallenius, 2004).

Our research showed that life in noisy areas changes the subjective relationship and attitudes of people towards the noise. The respondents from noisy streets rated noise as the most important risk factor ten times more frequently than respondents from quiet streets. Significantly greater noise annoyance found among residents of noisy streets caused that they gave much higher importance to noise as a most harmful environmental factor.

It is believed that the noise annoyance, as a negative attitude towards a specific noise or noisy environments, is the most common adverse effect of noise on people. Several authors showed dose-effect relationship between noise level and annoyance level (Sato et al., 1999, Miedema 2001, Klæboe et al., 2004.). The feeling of annoyance results not only from interference with communication and sleep disturbance, but also from less well-defined feelings of being disturbed and affected during all kinds of activities as well as during periods of rest.

The results of our investigation showed that road traffic and works on the street were the most important sources of noise for both groups. A study in Belgrade (Jakovljevic et al., 2009) also showed that residents rated road traffic much higher than the other sources of noise.

A group of scientists in Bratislava (Sobotova et al., 2006) also examined the percentage of subjects highly annoyed by road traffic noise, neighbourhood noise, noise from entertainment facilities, industry and railway noise. However, in this Slovakian study the highest risk of noise annoyance was connected to noise from entertainment facilities. Similarly, the study of Zannin et al. (2003) pointed out that residents may not consider traffic noise as the most important source of noise. The researchers were surprised to find that although the levels of noise were significantly decreased over a decade in the city of Curtiba in Brazil, the perception of noise annoyance among exposed population increased, mainly as a result of noise generated by the neighbourhood.

5. CONCLUSION

There is a substantial inter-individual variance of health effects of noise. A factor that might explain a part of this variance might be attitude towards noise which, in turn, can be influenced by place of residence as our results have shown.

6. ACKNOWLEDGEMENTS

The authors thank the Faculty of Occupational Safety in Nis for the results of noise measurements.

REFERENCES

[1] B. Berglund, T. Lindvall and D.H. Schwella, *Guidelines for community noise,* World Health Organization, Geneva, (1999).

[2] *ISO Acoustics - Description and measurement of environmental noise - Part I, Basic Quantities and procedures. International Standard. ISO 1996-1. International Organization for Standardization,* Geneva, 1982.

[3] B. Jakovljevic, K. Paunovic, G. Belojevic, *„Road traffic noise and factors influencing noise annoyance in an urban population"*. Environment International 35:552-556, 2009.

[4] R. Klæboe, A.H. Amundsen, A. Fyhri, S. Solberg, *„Road traffic noise – the relationship between noise exposure and noise annoyance in Norway"*. Applied Acoustics 6:59-72, 2004.

[5] H. Miedema, *„Noise and health: How does noise affect us?"*. Proceedings of Inter-Noise 1:3-20, 2001.

[6] T. Sato, T. Yano, M. Bjőrkman, R. Rylander *„Road traffic noise annoyance in relation to average noise level, number ov events and maximum noise level"*. J Sound Vibr 223:775-84, 1999.

[7] L. Sobotova, J. Jurkovicova, Z. Stefanikova, L. Sevcikova, L. Aghova *„Community noise annoyance assessment in an urban agglomeration"*. Bratisl Lek Listy 107:214-6, 2006.

[8] M. A. Wallenius, *"The interaction of noise stress and personal project stress on subjective health"*. J Environ psychol 24:167-177, 2004.

[9] P.H. Zannin, A. Calixto, F.B. Diniz, J.A. Ferreira, *„A survey of urban noise annoyance in a large Brazilian city: the importance of a subjective analysis in conjuction with objective analysis"*. Environ Impact Assess Rev. 23:245-55, 2003.

[10] *WHO Regional Office for Europe. Charter on Transport, Environment and Health Copenhagen: World Health Organization;* Available from http://www.euro.who.int/about/policy/20020221-1, 1999.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

NOISE-INDUCED HEARING LOSS – THE PLAGUE OF THE NEW MILLENNIUM

Dragoslav Ilić[1]

[1] Institute of Occupational Health, Nis

Abstract - *According to the perfection of its formation and function, the ear has no peer among other senses. Moreover, no other organ in the human body can be compared to its subtleness and delicacy.*

Situated in one of the hardest bones of the skeleton, it is relatively well-protected from rough mechanical injuries; however, it is not protected from one physical damage to which it remains not only completely powerless but also extremely vulnerable. That is communal noise, as an unwanted and, it seems, unavoidable effect of human action only.

Since there is virtually no effective defence against noise, in a relatively short time noise, which affects wide population, has become an enourmous strain on the ear, which - on its part - is unable to undergo evolutionary adaptation.

Thus, the inability of human beings to adapt to noise in their surroundings and resist it effectively culminated at the end of the 1950s, when a completely new disease appeared which now threatens to become a disaster at the beginning of the new millennium. That disease is noise-induced hearing loss, a complex disease having both auditory and extra-auditory effects on human beings.

Auditory effects are primary and manifested in hearing damage – in the so-called acoustic trauma, while extra-auditory effects are secondary (but by no means less important) and they include dysfunctions in many organs and systems in the human body.

Depending on the intensity and duration of noise, acoustic trauma can be acute or chronic, and it can be manifested in the form of partial or complete hearing loss, which can be conductive, sensorineural or mixed in type, depending on the mechanism through which noise affects the structure of the ear.

Occupational medicine is particularly interested in occupational partial or complete hearing loss. To recognize partial or complete hearing loss as a professional disease, it is necessary to meet strictly defined criteria.

Today about 12% of world population suffer from noise-induced partial or complete hearing loss in one way or another, while deafness is one of three most frequent bodily handicaps affecting people - right after blindness and paralysis. Being an incurable and progressive disease, noise-induced hearing loss results in the reduced work capacity both in white-collar and blue-collar jobs.

Key words: *noise-induced hearing loss, partial or complete hearing loss, auditory effects, extra-auditory effects, working capabilities.*

1. INTRODUCTION

About 500 million years ago life could leave the water and develop on the land. This moving, however, could have been fatal for hearing unless nature had been forced to simultaneously create the outer, middle and inner ears in a relatively short time (if we consider how slow evolution is). In this way, it gave land creatures the hearing organ which had no peer when it came to the perfection of its formation and function.

Each of the ears performs a special role. The outer ear collects sound waves from the surrounding air with the pinna, and then it directs them through the auditory canal to the middle ear, where a special transmission system accepts them. This system consists of: the eardrum, two shortest muscles and three tiniest bones in the body – a real masterpiece of nature. It can transfer sounds of optimal intensity from the outer space to the inner ear almost without any loss. In the process, thanks to its being both elastic and rigid at the same time, this system tones down loud sounds and amplifies soft ones, acting as a shock absorber at one moment and as a resonator at another. Its most important role, however, is that with an incredible ease it manages to bridge a great difference in resistance (impedance) which air and the liquid of the inner ear respectively offer to any kind of movement. This difference is 58-60 dB and it is a natural consequence of the different density of these two environments. If it were not for this transmission system, 99% of sound waves would bounce off the membrane of the inner ear, and only 1% would be absorbed. Practically, all land creatures, including our ancestor, would be deaf.

However, instead of using the earlier ear construction, nature used the already existing hearing bladder to create the inner ear, “borrowing” it from the fish. Primitive in form and of moderate capacities, this bladder would not have been able to deal with such an abundance of sound information from surrounding air, so it had to be remodeled. First, nature stretched it giving it a band-like form, instead of the until then known spherical shape, for one reason – in order to increase the space where a considerably great number of hearing receptors would be situated, ordered like the keys on the keyboard – from those which reacted to the lowest frequencies to those that reacted to the highest ones. To

locate this enlarged organ into the small bone structure, nature was forced to decrease it by winding it two and a half times along its vertical axis in the form of the spiral, thus giving it the final form of the snail. It made this engineering miracle for one purpose only: to act like the dynamo in the car engine – to transform the mechanical energy of sound pressure into electrical impulses. For this reason, the inner ear becomes the place where laws of biomechanics stop, while laws of bioelectronics begin working.

Working on the ear at the time of almost absolute silence, nature assumed that the ear did not need any special vascularization since it had low energetic need in order to deal with noise at moments of attack, defence or hiding. For that reason, the inner ear was and still is supplied with necessary food and energy (primarily, oxygen) exclusively indirectly - by perfusion through lymph, in which it is immersed. This "neglect" of nature would turn out to be fatal to our hearing centuries later.

It is known that each stage in the evolution of our civilization has tried to take something from nature and to force some of its surrogates on nature. The climax of this "bombardment" was reached in the second half of the 19th and throughout the 20th centuries. The industrial revolution, development of transport and especially new technologies has had a number of advantages but also one unwanted, but obviously inevitable, side-effect – a persistent increase in noise, whose presence becomes greater on a daily basis, despite the implementation of protective measures. Thus, according to the data of the World Health Organization, noise has become the third greatest pollutant of the environment – right after air and water pollution and we have begun to "pay the bill" for its destructive "services".

The proportions of its planetary expansion are expressed extremely vividly by Prof. Cvetkovic, head of the Noise and Vibration Laboratory at the Nis Faculty of Occupational Safety, beginning one of his papers on the topic saying: "Millions of human beings, subjects to the consumption of the benefits of technological revolutions, toils under the burden of decibel fetters". This, difficult to understand, masochism that the human being shows in relation to noise has had to produce the expected outcome.

Since there is virtually no effective defense against noise, an enormous noise-induced strain of hearing has affected the greater part of the population in a relatively short time, for which the human kind has not be prepared due to the ear not having any possibility for evolutionary adaptation. Actually, human inability to adapt to the noise level in their environment, as well as human inability to fight noise effectively, culminated at the end of the 1950s, when a completely new disease – **a noise-induced disease** – appeared, threatening to become a plague at the beginning of the new millennium. Complex as it is, this disease has both auditory and extra-auditory effects.

2. AUDITORY EFFECTS OF NOISE

The auditory effects of noise are primary and they are manifested in hearing damage – the so-called acoustic trauma, caused exclusively by the hearing section of the frequency spectrum. Depending on the intensity and duration of noise, this trauma can be acute or chronic. Acute acoustic trauma is rare, usually caused by an accident (shots, explosions) and is, as a rule, accompanied by the air-blast injuries of the respiratory and internal organs. It appears after a short, momentary noise of high intensity which primarily damages the structure of the middle ear. Chronic acoustic trauma is much more frequent and is a consequence of a long-term exposure to excessive noise of variable intensity, which primarily affects the structures of the inner ear. It has been noticed that the human being is more susceptible to reacting to variable rather than constant noise, just as it is to high-frequency noise rather than low-frequency one. For example, out of two different sounds of the same intensity, the higher one will seem louder to us.

Clinical manifestations of acoustic trauma are partial or complete hearing loss. Depending on the degree of the hearing deficit at the level of the hearing threshold, partial hearing loss can be: insignificant (up to 20 dB), minimal (20-40 dB), moderate (40-60 dB) and severe (60-80 dB), while complete hearing loss represents a considerable hearing loss with the hearing deficit higher than 80 dB and can be practical (minimal hearing) or absolute (no hearing at all).

Depending on the mechanisms with which noise damages the anatomical structures of the hearing organ, both partial and complete hearing loss can be: conductive, sensorineural or mixed in type. Conductive partial and complete hearing loss respectively is caused by the direct impact of noise on the transmission system of the middle ear, resulting in its mechanical destruction or its degeneration (tympanosclerosis). Sensorineural partial and complete loss appears as a result of an indirect influence of noise on the inner ear, which is relatively well protected from rough mechanical damages due to an extremely hard temporal bone where it is situated (it can hold the pressure of 100 tons without bursting) but is absolutely powerless when it comes to the effects of noise and, surprisingly, shows a high degree of vulnerability.

Why is the inner ear so susceptible to noise? The answer is the already mentioned "neglect" of nature, which has deprived it of adequate vascularization, thus condemning the inner ear to permanent "starvation". Therefore, its highly-differentiated and energetically highly-demanding cells are on the verge of hypoxia even under normal everyday conditions. Acting indirectly on the vasomotor center in the spinal cord, noise induces vasospasm of all brain arteries, including inner hearing arteries, reaching only up to the middle ear. In this way, noise compromises already deficient nutrition and energetic supply of the inner hearing arteries; consequently, in the newly-established conditions of ischemia and anoxia, the beginning of the degenerative process in the ear cells (otosclerosis) is inevitable.

Partial and complete hearing loss of mixed type appears as the result of the middle and inner ear damage, which is most frequently the case. For occupational medicine, hearing damage caused by noise exclusively related to work environment as a byproduct of the technological process is of particular importance. As a rule, work-related hearing damage is bilateral, perceptive, progressive, irreversible and irreparable – thus, permanent. Today about 12% of world population suffer from noise-induced partial or complete hearing loss in one way or another, while deafness is one of

three most frequent bodily handicaps affecting people - right after blindness and paralysis.

3 EXTRA-AUDITORY EFFECTS OF NOISE

Extra-auditory effects are secondary, but by no means less important. They are manifested in the dysfunction of a number of organs and systems in the human body, induced not only by auditory but also non-auditory sections of the frequency spectrum (infra- and ultra-sound). The inducers of these disorders are located in the brain, or more precisely, in the thalamus. It is assumed that these are acoustic nuclei, which belong to the so-called acoustic pathway, which impulses normally use to move from the inner ear to the cortical auditory centers.

Since these nuclei are connected to the lower centers in the spinal cord by bidirectional relay pathways, impulses can use these relay pathways to partly turn to the lower parts, inducing a vegetative "complications", mostly: in the nervous system (motor slowness, reduced precision, discoordination of voluntary and reflex movements, sensory complications, especially in the area of audio-visual perception; psychological disorders, such as anxiety, insomnia, irritability, poor concentration etc); in the cardiovascular system (speeded heart beat, arrhythmia, blood pressure increase, vasoconstriction of blood vessels); in the digestive system (increased secretion of the gastric acid, pyloric spasm, increased intestinal peristalsis, irregular stool); in the endocrine system (increased level of hormones of the adrenal and thyroid glands, decrease in the insulin level in blood, increase of basal metabolism); in the hematopoetic system (hematopoiesis-related disorders – an increase of white blood cells, lower albumen synthesis, immune system disturbance); in the sense of sight (visual field narrowing, poor colour recognition, pupil dilation and accommodation disorders); in the balance systems (stability disorders, vertigo and nausea). There can also be menstrual cycle disturbances, pregnancy (miscarriage, premature birth) and loss of lactation in women, while in men there can be: a decrease in libido, in virility and even sterility.

Auditory and extra-auditory effects of noise can, among other things, affect work capabilities of white-collar as well as blue-collar laborers. Since adaptation to noise is minimal, moise easily contributes to a decrease in labor quality and productivity (20-25%) and to the presence of fatigue, which, on the other hand, becomes the direct and major cause of a large number of work injuries and accidents. This has probably urged the renowned Professor Miodrag Simonovic to ask in his extraordinary monography *Audiology*: "Is working in a noisy environment pointless?"



23rd NATIONAL & 4th INTERNATINAL CONFERENCE

NOISE AND VIBRATION



STUDENT PAPERS

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

SUPPORTING CONSTRUCTION OF SOUND BARRIERS

Marija Marković[1], Nikola Odalović[1]
mentor: Prof. dr Milan Kolarević[1]

[1] University of Kragujevac, Faculty of Mechanical Engineering Kraljevo, Serbia, mari.mark@gmx.com

Abstract - *Sound barriers are used to reduce the intensity of level noise sources which are primarily road, rail and other forms of transport that is endangering the environment. Since the barrier can be exposed to significant loads such as wind load, snow, etc. it must be designed to meet the demands in addition to acoustic and other conditions. This paper presents different construction solutions of supporting structures as sound barriers and their classification.*

1. INTRODUCTION

Sound as an integral part of everyday life, the human environment, the companion of many life activities is manifested from the finest natural sounds, speech, sounds that are a consequence of human activities in the working and living environment to unwanted sounds that cause harmful effects on the human body. Unwanted and harmful sound to the environment is **noise** [1]. Resting in the garden listening to the birds is different and certainly more enjoyable than relaxing in the garden surrounded by traffic noise [4]. To prevent this, especially in densely populated areas in the design of buildings whose purpose is of public character (resorts, hotels, hospitals, kindergartens, schools, etc.) a requirement for setting up sound insulation is often. The increase in the number of infrastructure projects, especially roads and railways, leading to increased demands for reduced noise levels. This is achieved by placing the protection of sound, usually sound barriers.

2. SOUND BARRIERS

Under the protection from sound implies a set of measures that ensures that the sound transmission from the source to the receiving stations is weakened [1]. Sounds barriers (acoustic screens) reduced a level of noise on satisfactory level by preventing the propagation of sound waves. Practically reducing of sound level by using reflection barriers which are in range from 10-15 dB(A), and applying absorption barriers this effect can be better for additional 5 dB(A) [5]. Figure 1 is showing the principle of work of sound barriers, actually on which way sound barriers reduce sound using reflection, absorption, transmission and diffraction.

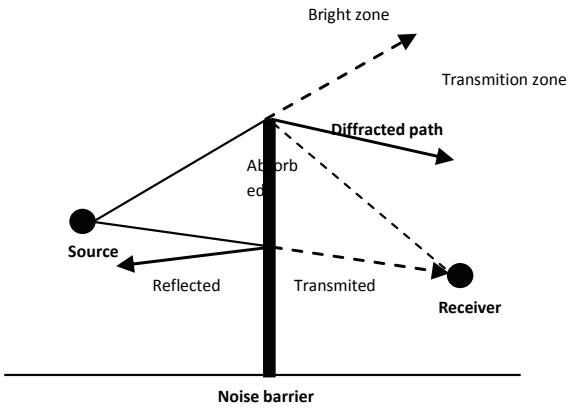


Fig. 1 *Schematic overview of the principles of sound barriers [4].*

Sound barriers are used for:

- sound protection of objects (buildings, building construction) and
- sound protection in external space [1].

Sound protection of objects are realized with the appropriate design solution and the layout, actually with performance of sound insulation inside the building.

Sound protection in external space are provided with outdoor space, acoustic planning, urban solutions, sound barriers etc [1].

Sound barriers can be of various shapes and structures. The barriers aren't made from a big number of parts, they can even be built from a portion (Figure 2), but the structural components of these solutions can significantly affect the characteristics of the sound barriers.



Fig. 2 *Poured concrete barrier.*

The main modules of barrier (Figure 3) are:

1. Foundation
2. Wall of barrier (panel)
3. Support construction

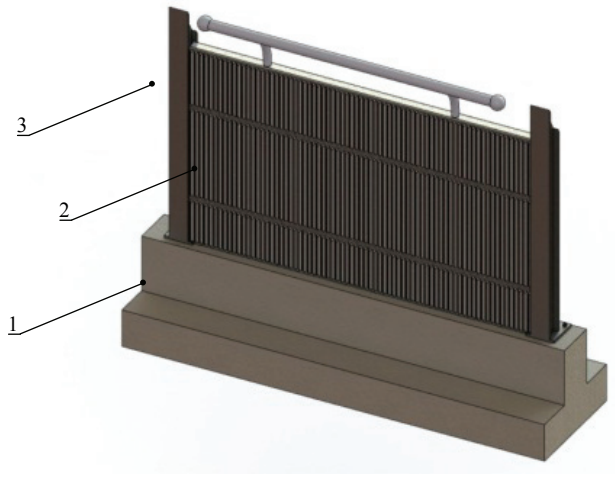


Fig. 3 *The main modules of barrier*

An important factor in the design of the barrier is her shape of profile that can be vertical, tilted at an angle, partially hollow and cantilever [5].

In the process of designing barriers, it is important to pay attention to the configuration of the land on which sound barriers will be built, as well on environment. In accordance with that are adopted and different combinations of design solutions for sound barriers (Figure 4).

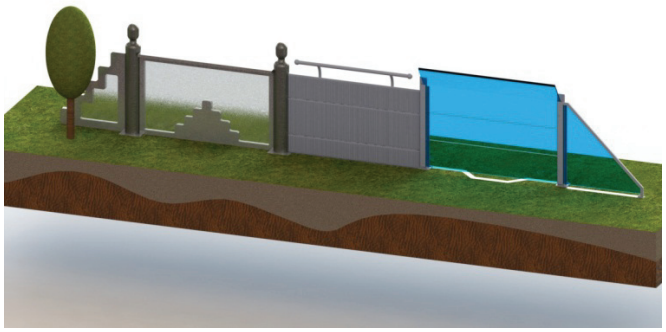


Fig. 4 *Different design solutions of sound barriers that affect the reflection and absorption of noise and aesthetics [5].*

3. SUPPORT CONSTRUCTION

3.1 Basic concepts

As it was mentioned in the previous chapter barriers can be of various shapes and structures. They can be composed from several parts or only one. In any case, the barriers are exposed to significant loads, especially wind load, and should therefore be designed to meet the appropriate requirements. In order to meet this conditions, the existence of supporting structure is necessary.

Basic elements of support structure are:

- Support profiles (posts)
- Connecting elements
- Additional support profiles
- Stiffenings

3.2 Support profiles

Support profiles (columns) have an important role in the design and installation of sound barriers. They represent one of the main parts of the sound barrier as they provide support against the influence of various loads, for example the effects of weather, and therefore needs to be designed to meet the appropriate requirements. They can be in different forms, depending on the load (Figure 5), and as far as aesthetics goes they can be visible, hidden from one side and hidden from both sides (Figure 6).



Fig. 5 *Different shapes of support profiles*

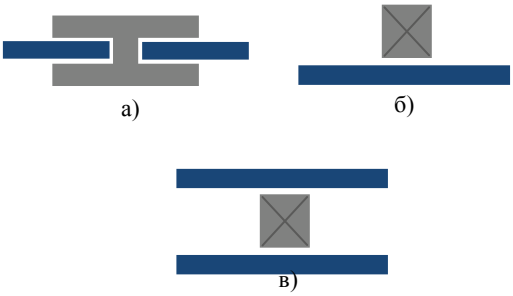


Fig. 6 *Support profiles from aesthetics side. a) visible, b) hidden from one side, в) hidden from both sides*

3.3 Additional support profile

For modular sound barriers, at high loads and between large spans where a smaller number of supporting pillars is present, in addition to suport profiles, additional supporting profiles are needed to provide lateral structural support for acoustic panels. This is achieved by additional supporting profiles (Figure 7).



Fig. 7 *Lateral structural support*

Like the other parts of the barrier, the profiles required for additional supporting need to undergo a comprehensive examination by the design team. They are part of the support structure that provides additional support for barriers that are under the influence of great pressure and stress. When designing modular barrier profiles for supporting they can be aesthetically complex (concrete and metal, Figure 8) or simple (concrete and metal, Figure 9).



a)

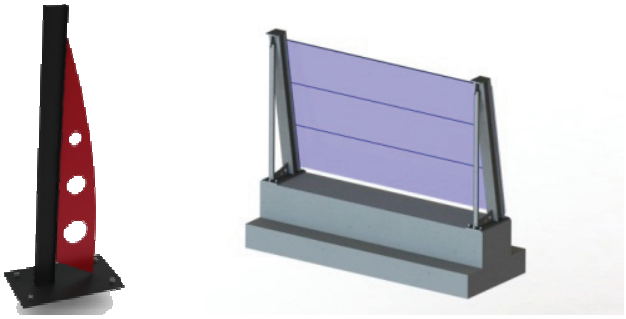


b)

Fig. 8 *Examples of aesthetically complex profiles: a) concrete, b) metal*



a)



b)

Fig. 9 *Examples of aesthetically simple profiles a) concrete, b) metal*

3.4 Connecting elements

As most of the modular barrier consists of a sound panels that are positioned between the vertical supporting pillars, it is necessary to attach the panels to the posts and pillars for concrete-foundation. Fastening elements, or connecting elements allow easy installation of barriers at the site and easy removal or replacement of damaged barier parts such as panels.

Connecting elements are very simple parts. Fastening elements that are commonly used (Figure 10) are:

1. with flexible inserts,
2. flanges,
3. connections between support construction and foundation with bolts,
4. complex connections.

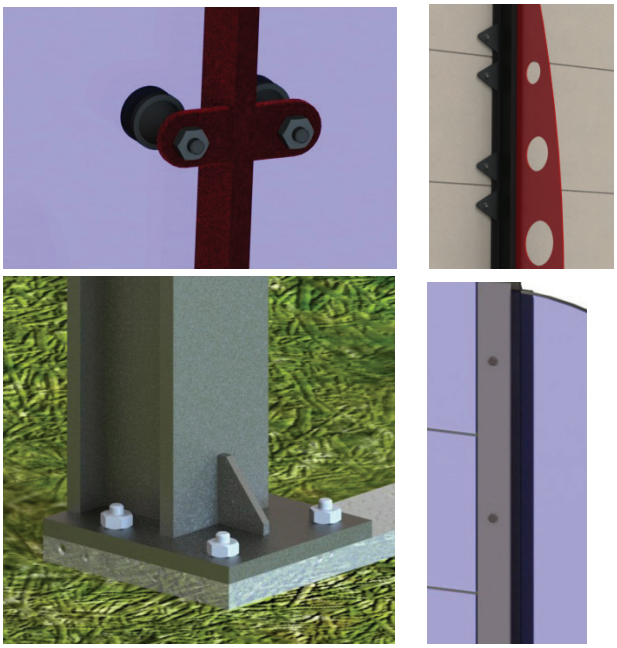


Fig. 10 *Connecting elements*

3.5 Stiffening

Stiffening (Figure 11) represent a part of support structure which are used when it's need to achieve bigger rigidity of complete structure of sound barriers. The function of stiffening is reducing of moves out of limits, predicted with design, which can be due to load.

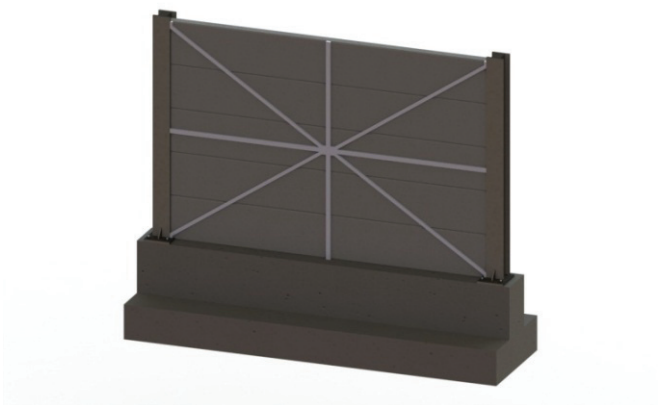


Fig. 11 *Stiffening*

4. CONCLUSION

Population growth in cities leads to increased traffic and therefore to a larger sound pollution. Sound barrier in a modern environment strives to provide the best possible conditions for life by becoming more and more important. So they need solutions that will be functional, aesthetic, easy to produce and easy to maintain. Application of modular design facilitates analysis morphology of sound barriers as well as the process of designing and manufacturing process of sound barriers.

Modern concept of structural support of sound barriers is presented of the mind map shown in Figure 12.

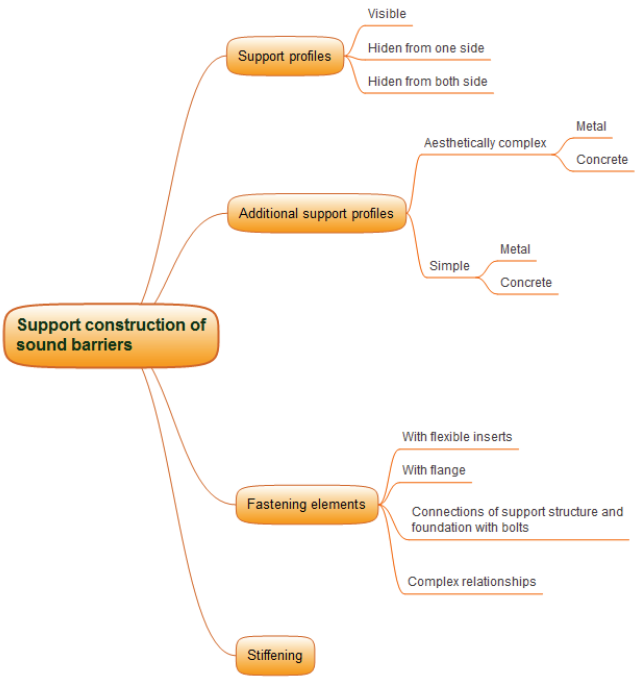


Fig. 12 *Concept of structural support of sound barriers.*

REFERENCES

[1] http://sr.wikipedia.org/wiki/Buka

[2] M. Praščević, D. Cvetković: *Environmental Noise*, University of Niš, Fakultet zaštite na radu, Niš, 2005.

[3] G. G. Fleming, H. S. Knauer, Cynthia S.Y. Lee, S. Pedersen: *Noise Barrier Design Handbook, Highway Traffic Noise*, http://www.fhwa.dot.gov/environment/noise/noise_barriers/design_construction/design/index.cfm

[4] B. Kotzen, C. English: *Environmental Noise Barriers , A guide to their acoustic and visual design*, Second edition, Taylor & Francis e-Library, London and New York, 2009.

[5] V. Grković, M. Kolarević, Z. Patrović, M. Vukićević: *Morphology of Modular Traffic Noise Barriers*, 4th International Conference Noise and Vibration, Niš, 2012.

University of Nis
Faculty of Occupational Safety
„Politechnica“ University of Timisoara
Faculty of Mechanical Engineering
23rd National Conference &
4th International Conference
NOISE AND VIBRATION
Niš, 17 - 19. 10. 2012.

TECHNICAL SOLUTIONS FOR DIFFERENT TYPES OF BARRIER TOP

Dragana Sladoje ,Bojana Velickovic
Mentor: Prof. dr Miomir Vukicevic

University of Kragujevac, Faculty of Mechanical Engineering Kraljevo, Serbia

Abstract – *Noise barriers are exterior structure designed to reduce noise level and to preventnt spreading of sound waves. This paper shows technical solutions for different types of barrier top. Noise barrier function is conditioned by reducing of the noise level on the side of the receiver. Special attention is given to their physical and aesthetic importance to the environment that they are set into.*
Key words: *communal noise, barrier, barrier top, construction.*

1. INTRODUCTION

The rapid development of modern society, since the beginning of the twentieth century, the construction of new roads, industrialization, have led to a new environmental problem – noise. Thus, the need for low noise environment has increased. One of the solutions is the creation of a physical obstacle to its expansion. Strong market of different types of noise barriers has developed.

Noise barriers are exterior structure designed to reduce noise levels and to prevent spreading of sound waves. According to their type, barriers can be divide by:

1. Mode of action:
   - reflective,
   - absorbing,
   - with rezonants.
2. Form:
   - sound wals: vertical, cantilevered,
   - tunnels: semi-open, closed,
   - earth mounds: and planting, without planting,
   - the combination of barriers and mounds.

Without barriers direct spreading of sound waves is enabled between the source and the recover. By setting the barrier the part of energy is reflected from the wall, part is absorbed by the barrier, and a part weakened by the insulation characteristics of the barrier moves on to the recover, fig. 1. Due to the effect of diffraction, part of energy is bent around the top and side edges of the barrier and continues to move to the recover[1].

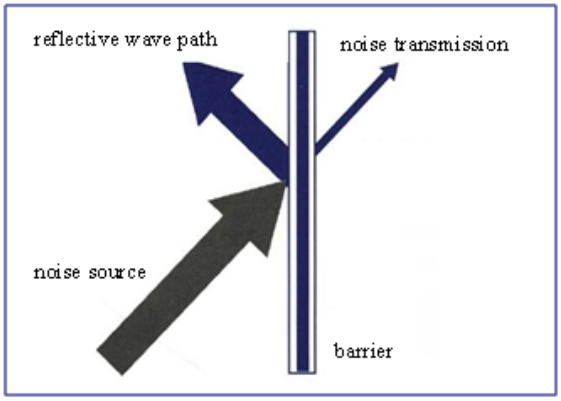


Figure 1. *Transition of the sound waves*

There are some negative effects of placing the barrier, such as the level of noise on the side of the source. If the barrier is placed on both sides of the source (egg. roads), multiple reflections of the sound waves contribute to the increasing level of noise on the side of the recover. These negative effects can be reduced by barrier coating with absorbing materials on the side of the source, which reduces the reflected energy.

2. BARRIER FUNCTION

Design of the noise barriers is conditioned with reduction of the noise on the recovers side. Barrier design should meet two types of requests:

a) acoustic:
   - reduction of the noise level on the recivers side,
   - reducing the increase in noise on the side of the source,

b) nonacoustic:
   - appearance of the barrier,
   - safety,
   - maintenance.

The degree of reduction of the noise level is determined by:

- barrier location,
- barrier material,
- barrier dimensions,
- The shape of the barrier.
-

2.1. Barrier location

In order for the barrier to have the desired effect, it is placed between the source of the noise and the receiver in such manner that it prevents their direct visibility that is to prevent direct spreading of the noise. When designing a barrier it is

important to prevent direct flow of the sound from source to the receiver through the gap in the barrier section, or through various types of gaps, holes, cracks or other types of spaces. This significantly reduces the effect of the barrier because it is considered that the flow of sound to the receiver is a 100% in these places.

2.2. Barrier material

Significant impact on the design of the barrier has different types of the materials. Each material allows a certain amount of noise to spread, but it depends on the type of the material and the noise frequency. In order for the barrier to be effective it is important to pay attention that the amount of noise that flows through the material is considerably smaller than the one that goes over the top of the barrier or around its edges.

Barrier dimensions and aesthetics are important items to its design. Noise barrier should be of sufficient size to fully visually separate the source and the receiver (both length and height). Whereas aesthetics goes, barriers should be incorporated into the overall appearance of the surroundings where it is placed. This has further caused different project solutions and barrier types which do not impair the visual effect of the environment.

2.3. Barrier dimensios

Noise barrier must be high enough and log to block the view to the highway or another noise source from the area that is being protected. Nosie barrier achieve very little effect in comunities located on the hills or buildings that are above the barrier. Barriers can reduce noise up to 5 dB, when the barrier is high enough to brake the line of the sight from the highway to the community or reciver. When the barrier is high enough to shield the sight of the reciver, noise reduction of up to 1.5 dB is achieved per meter of the barrier height (figure 2).

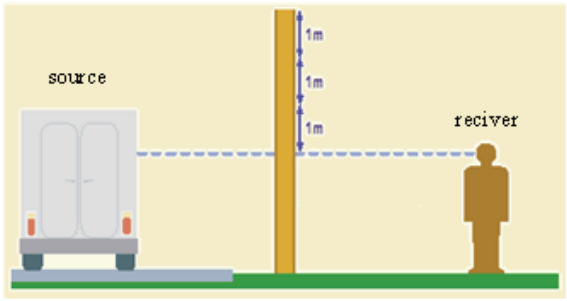


Figure 2 *The imapct of the height of the barrier*

2.4. The elements of the barrier

In order to properly describe and analyze noise barriers it is important to create a simple morphology. This has enabled to describe a barrier, and each of its components individually as to understand the appeal of specific aesthetic solutions in relation to the others.

Classification and the structure of the barrier, is not complicated in its basics because each barrier is structurally divided into their main parts:

- base,
- the middle section,
- top.

This division is observed at each barrier, figure 3, so this applies in cases where the barrier is constructed from one material.

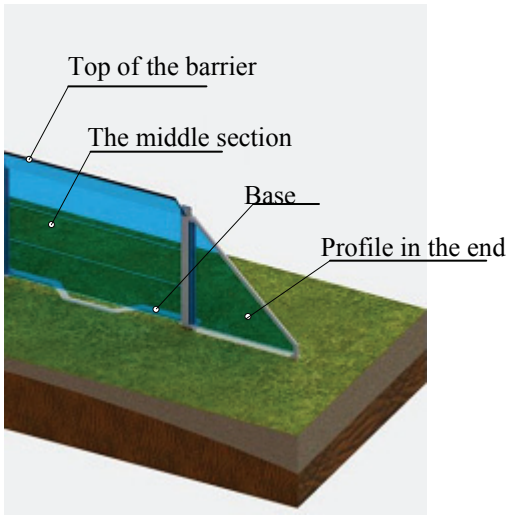


Figure 3 *Barrier morphology*

Top of the noise barrier is an extension to the existing barrier in order to improve the ability to reduce noise. This section of the barrier defines the general characteristics and the form of the barrier.

Top of the barrier is critical to its aesthetic appearance when viewed in the background. Accordingly, top of the barrier is designed to complement the background of the environment, or to stand out. This depends of the location that the barrier is designed for. Thus, for example, if the barrier is designed for an urban environment, it is necessary to take into account the aesthetics of the environment, as well as the fact that for an average pedestrian eye level is 1.5÷1.7 m. This means that in these areas top of the barrier will present a silhouette for a pedestrian. For observers from the car eye level is lower, 1.3÷1.4 m, which means that the barrier will be observed upwards. This is the reason why the top of the barrier is often left out of the design process, in order to make a stronger aesthetic impression or for the barrier to fit into the environment better. If it is dicused of a rural area, barriers are mostly designed to be transparent in order to better fit into the enviorment, and not to disturb the appearance of the nature.

3. TYPES OF THE BARRIER TOPS

To the top of the barriers, figures 4 to 10, the visual appearance is very important and whether it fits into the environment, thus allowing the designers to, in most cases, in order to improve the aesthetic appearance of the barrier design special forms of the barrier tops. Hence, most of the barriers have a simple and unobtrusive design.

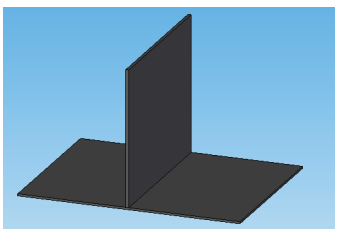


Figure 4 *Panel profile*

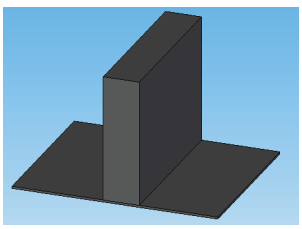


Figure 5 *The rectangular profile*

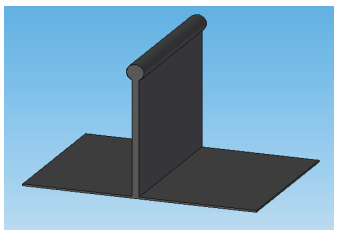


Figure 6 *Cylindrical profile*

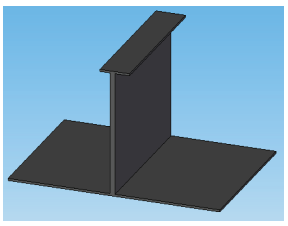


Figure 7 *T–profile*

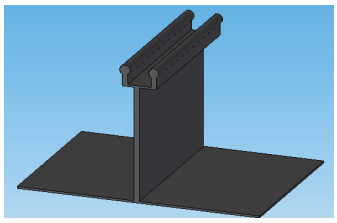


Figure 8 *Dual cylindrical profile*

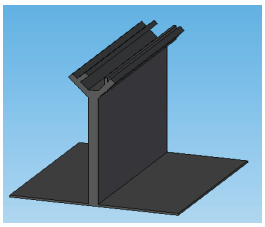


Figure 9 *Branched profile*

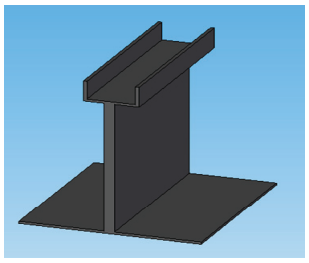


Figure 10 *Profile with multiple edges*

3.1. Special forms of barreier tops

Studies have shown that special forms of barrier tops create the effect of diffraction and reduce the noise level. Other than diffraction elements such as T–profile, Y–profile, arrowed profile etc. at the top of the barrier tubular absorbers with cross-section of a ball or pear will be placed. Application of the special shapes of the top of the barrier additionally reduces the noise for 1÷2.5 dB (A) which enables the reduction of the barrier height. Lower barriers reduce the level of environmental shielding which could improve the aesthetics effects to the environment.

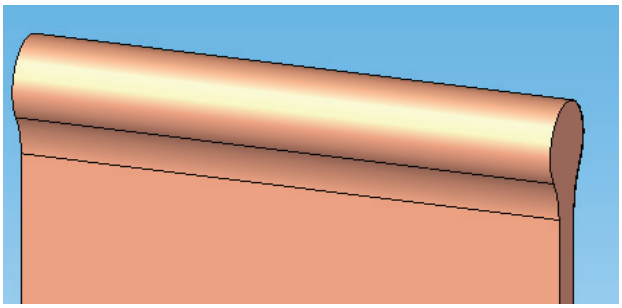


Figure 11 *Special shape of the barrier, Y –profile*

Although top of the barrier have certain acoustic and aesthetic benefits, the expences of their construction usually exceed the costs of higher barriers with classic form of the top which achieve the same acoustic benefit, thust causing this trend to disappear.

4. CONCUSSION

During the first decade of the twenty-first century, in most cases, during the process of barrier design the top of the barrier has been left out in order to control and simplify the design process. In studies testing the tops of the barriers various types of barrier tops have been tested. As the most efficient one in practical situations the T–profile has shown as the best solution from the point of noise reduction.

In more recent studies new types of barrier tops have been tested. One of these types is the random set of spikes placed as the top of the barrier, figure 12. The results of this study has shown that the barrier with random set of spikes and the same height as the barrier with flat top (figure 13), significantly reduces the noise level on the recovers side compared to the flat top.

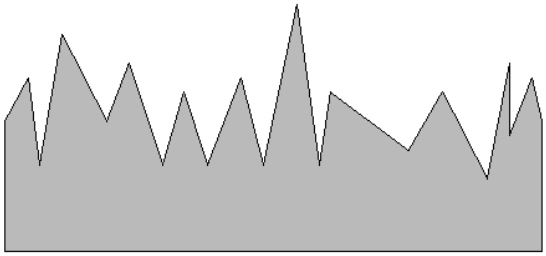


Figure 12 *Barrier top with random spikes* [4]



Figure 13 *Barrier with flat top* [4]

REFERENCES

[1] B. Cozen, C. English: *Environmental Noise Barriers, A guide to their acoustic and visual design*, Second edition, Taylor & Francis e-Library, London and New York, 2009.

[2] G.G. Fleming, H.S. Knavery, Cynthia SAY Lee, S. Pedersen: *Noise Barrier Design Handbook, Highway Traffic Noise*,

[3] *Highway Traffic Noise Analysis And Abatement Policy And Guidance* by U.S. Department of Transportation, Federal Highway Administration, Office of Environment and Planning Noise and Air Quality Branch, Washington, D.C., June 1995

[4] www.acoustics.org

[5] G.G. Fleming, H.S. Knavery, Cynthia SAY Lee, S. Pedersen: *Noise Barrier Design Handbook, Highway Traffic Noise*, http://www.fhwa.dot.gov/environment/noise/noise_barriers/design_construction/design/index.cfm



Brüel & Kjær