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ADAPTIVE NOISE REDUCTION SYSTEM

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"*The day will come when man will have to fight noise as inexorably as cholera and plague.*" - Robert Koch, 1905.

ABSTRACT

Noise is an all-present environment pollutant, considered to be one of the greatest contemporary pollutants. World-wide, co-ordinated actions are conducted in order to develop systems which minimise the noise influence onto society.

In this article we argue that novel approach to suppression of influence of noise is useful. Furthermore, we argue that the efficient approach is formulation of the efficient, broadly applicable, ubiquitous, adaptive noise-protection system. The approach combines the natural noise-protection form based on plants with the artificially formed coatings.

Elements of the system are discussed, its formation and maintenance analysed and perspectives conjectured.

KEY WORDS

noise, sound damping, adaptation, nanotechnology

CLASSIFICATION

JEL: A55, Q53

PACS: 43.40.+s, 43.50.+y

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INTRODUCTION

Noise is defined as any undesirable sound in the place where people live and work, which causes annoyment or can be even harmfull for health [1]. World Health Organization in its reports refer noise, by water and air, as one of three main pollutant of human enviroment [2]. Thus the statement of the Nobel prize-winning bacteriologist Robert Koch, writen previously, became a reality. Noise manifests complexity of modern world. There is rarely a particular source of noise that can be modified, but prevalently noise is aggregated consequence of a large number of aspects of modern life: machines, vehicles, processes, human themselves, etc. There seems to be a certain level of noise accompanying some technical level of a civilisation, yet stringent efforts should be involved in research and development of noise reduction in order to preserve that level within acceptable limit for humans. In that way, regarding noise, civilisation should achieve sustainable development in which noise is limited within a certain limit.

Noise pollution increases every day. Estimated 20 % of EU population, approximatelly 80 million people, suffers from noise levels that scientists and health experts consider to be unacceptable. Because of that, life conditions of a lot of people has changed, with consequences ranging from e.g. their sleep being disturbed to e.g. permanent health problem of some of them, such as is hear loss. Furthermore, approximatelly 170 million citizens live in so called *grey areas* where the noise levels are such to cause serious annoyance during the daytime. The problem of too intense noise is treated implicitly by the EU Directive 2002/49 which refers to the assessment and management of environmental noise [3]. In particular, that statement addresses the need to monitor the environmental problem (along with drawing "strategic noise maps"), to inform and consult the public about noise exposure and its effects, to address the local noise issues by requiring competent authorities to draw up action plans to reduce noise where necessary and maintain environmental noise quality where it is good, and finally to develop the long-term EU strategy [4].

There exists a significant number of types of noise sources. Many times people exposed to these sources are not aware what is a source of observed noise. The prevalent noise sources are traffic noise, working devices and activities conducted.

Since a long-time ago, globally a part of noise protection of workers has been a workplace safety. As a consequence, many countries have their Workplace safety laws and related regulations. The corresponding EU-level regulations are the Control of Noise at Work Regulations from 2005. The aim of the Noise Regulations is to ensure that workers' hearing is protected from excessive noise at their place of work, which could cause them to lose their hearing and/or to suffer from tinnitus (permanent ringing in the ears) [4].

While on the one hand listed regulations and other legislatory measures clearly demonstrate the large efforts that society involves to solve or reduce the problem of too intense noise, on the other hand the problem is stil far from being solved on a satisfactory level. One approach to contributing to the noise-level suppression in urban regions is to enhance the efficiency of noise barriers by approapriate, innovative constructions.

In this article, we combine the two existing sets of noise barriers, the natural and the artificial barriers and treat them as a system with variable amount of artificial character (or, conversely of natural character). We argue that such a system, with variable amount being the adaptive parameter, enables people to reduce existing noise levels in a larger amount than if the sets of noise barriers are not combined in an adaptive manner.

The second section presents facts about the noise and its impact onto humans, third section discusses in some details existing sets of noise barriers along with the description of their adaptive combination. Fourth section presents conclusions and provides the readers with perspectives of the described approach.

THE NOISE AND ITS IMPACT ON THE HUMAN HEALTH

Noise in an internal working space (or, generally for indoor locations) occurs from few basic sources: internal disturbances, external noise and structural noise which is carried out by the infrastructure such as is a building. Consequently, there are three approaches to noise reduction: noise reduction directly at the location of the noise source, noise reduction between the source and the observer and noise reduction directly at the location of the observer.

Let us concentrate onto the indoor protection from external noise. These external noises include noise originating in external space or noise originating in neighbouring rooms and pursued by sound insulation. For efficient sound insulation it is important (i) to decrease sound pressure emited from the sound source, (ii) to decrease surface area connecting two rooms, (iii) to increase absorption in receiving room, and (iv) to increase sound insulation of existing barrier [5]. Further in the text we will focus on the effects of sound insulation onto the noise reduction.

Along with the noise-protetion of working place, it is important to protect people from envirometal noise pollution in their living places. Somewhat poetically, current status of the living place pollution by noise is that *silence does not live in our enviroment anymore*.

Noise exposure has a cumulative effect. Harmful impact of noise is observable after longer time and manifests itself as changes of mood, being tired, insomnia, headaches, concentration loss (e.g. loss of work capability) and eventually as the permanent hearing loss. Quantitatively, longer exposures to noise of 80 dB can bring about the temporary or permanent threshold shift. It is considered that relaxation period of duration of 16 h is necessary to rehabilitate a person who was exposed to noise at 85 dB for 8 hours. At the sound pressure of 140 dB it is possible to lose balance [6]. During verbal communication persons surrounded with noise unconsciously talk louder and longer exposures to noise cause voice disorders.

NOISE BARRIERS

NOISE PROTECTION BY NATURAL STRUCTURES

One of the noise protection ways is the use of plants.

In large urban areas, because of a heavy traffic, noise significantly degrades the quality of living. Transportation capacity and average speed cause visual and auditory pollution in urban areas.

Different barriers are utilised to block or reduce the noise in urban areas. For example, in researches about the noise levels in Ankara [7] the authors concluded that plants reduce the environmental noise, with different types of plants differing in sound insulation characteristics. In particular, *Hedera helix, Rubus fruticosus, Polygonum auberti, Parthenocissus quinquefolia* revealed efficient noise reduction [7]. Furthermore, that study extracted 16 deciduous plant species that can be used as noise curtain for Ankara, as well as 14 coniferous species that can be used both to absorb the noise and to block the wind effect in Ankara. According to the results of the research conducted, with a noise curtaining of three rows, the amount of noise has been reduced by 5 dB, which means that the perception of noise by people was halved [7].

Reducing the environmental noise by plants is more complete if a tree or a bush curtain is closer to the noise source, further to the region to be protected. The reason is that in such cases larger portion of acoustical energy is absorbed and scattered in diverse directions including the directions to the atmosphere.

Plant *Viburnum rhytidophyllum* protects from a noise throughout the year. Its evergreen leaves are wrinkled, with their length ranging from 18 cm to 25 cm. Their shape and dimensions are causes of the capability of that plant to reduce noise. That plant is known as “bush of donkey ears” [2]. Figure 1 sketches the general influence of that and other similar plants onto environmental noise. In Figure 1a, spectrum, a frequency dependence, of noise level is shown. In the absence of a plant it is assumed that noise level spectrum is horizontal line through most of the frequency region, except the high frequency region as it is attenuated even in the air. The lower the value of noise level, correspondingly, the larger the reduction of noise caused by plants. The complex frequency dependence of the plant’s influence is related to non-trivial frequency dependence of scattering of acoustical waves on the collection of geometrically highly irregular objects, leaves and branches. Before proceeding, let us note that plant’s influence is significant both in the high- and the low-frequency region, the regions in which the least part of the human speech is conducted, and at the same time the regions the sounds within which annoy humans above average. The minimal influence of plants on the noise level, what in Fig. 1a means the local maxima of the noise level, occurrs at frequencies of approximately 1 kHz [8]. Figure 1b sketches the difference in noise level, and correspondingly in the noise level reduction, because of the seasonal variations of some general plant. For constant intensity of noise source, the noise level is lower in summer because of the larger density of vegetation of plants, andthus of the denser collection of scatterers.

While influence of diverse plant species onto noise level mutually differs, general trend of that, natural barrier to noise is as shown in Fig. 1.

NOISE PROTECTION BY COATINGS

Coatings are ony type of artificial noise reduction. Among large variety of ways in which materials in different geometries and different textures reduces the ambient noise, let us use an illustratory case study to discuss in some detail the noise reduction related characteristics of a water-based coatings. In experimental study by Fan et al. [9] it was determined that damping

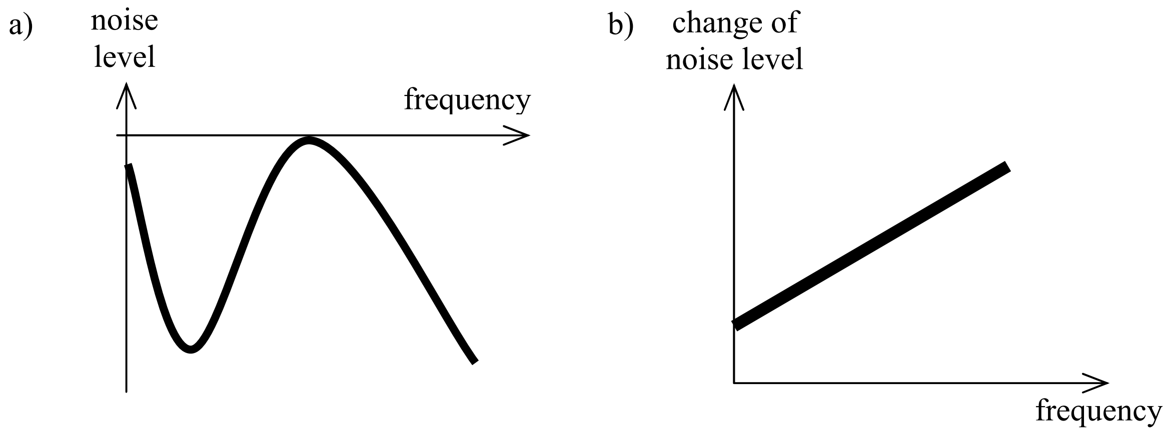


Figure 1. Impact of plants onto enviromental noise: a) noise level spectrum in vicinity of plants. Zero value of the ordinate corresponds to the absence of noise reduction and negative values generaly represents reduced noise, b) difference of noise level in summer and in winter (adapted from [8]).

material with water-based coating decreases the unweighted rms acceleration of the fundament. Since the vibrations causes acoustical disturbance in neighbouring atmosphere, i.e. the noise, their suppression is a significant contribution to noise level reduction by the previously listed approach, noise reduction directly at the location of the noise source. Without coating, that acceleration was typically in the range from 0,08 m/s^2 to 0,79 m/s^2. With the described coating the corresponding range was from 0,06 m/s^2 to 0,49 m/s^2. It was further discovered that vibrations can be reduced in considerably broader frequency bandwith by utilising the bitumen-based damping material than by utilising the butyl rubber damping material. The damping treatment of coated objects can reduce the dominant components of noise spectrum in the frequency region from 25 Hz to 160 Hz.

One may argue that the rapid development of new materials (foams, composites, coatings...) and of nanotechnology (and consequently of nanotechnologically treated) coatings for noise protection brings about the additional potential for further improvement of the acoustically damping coatings and innovative production of new types.

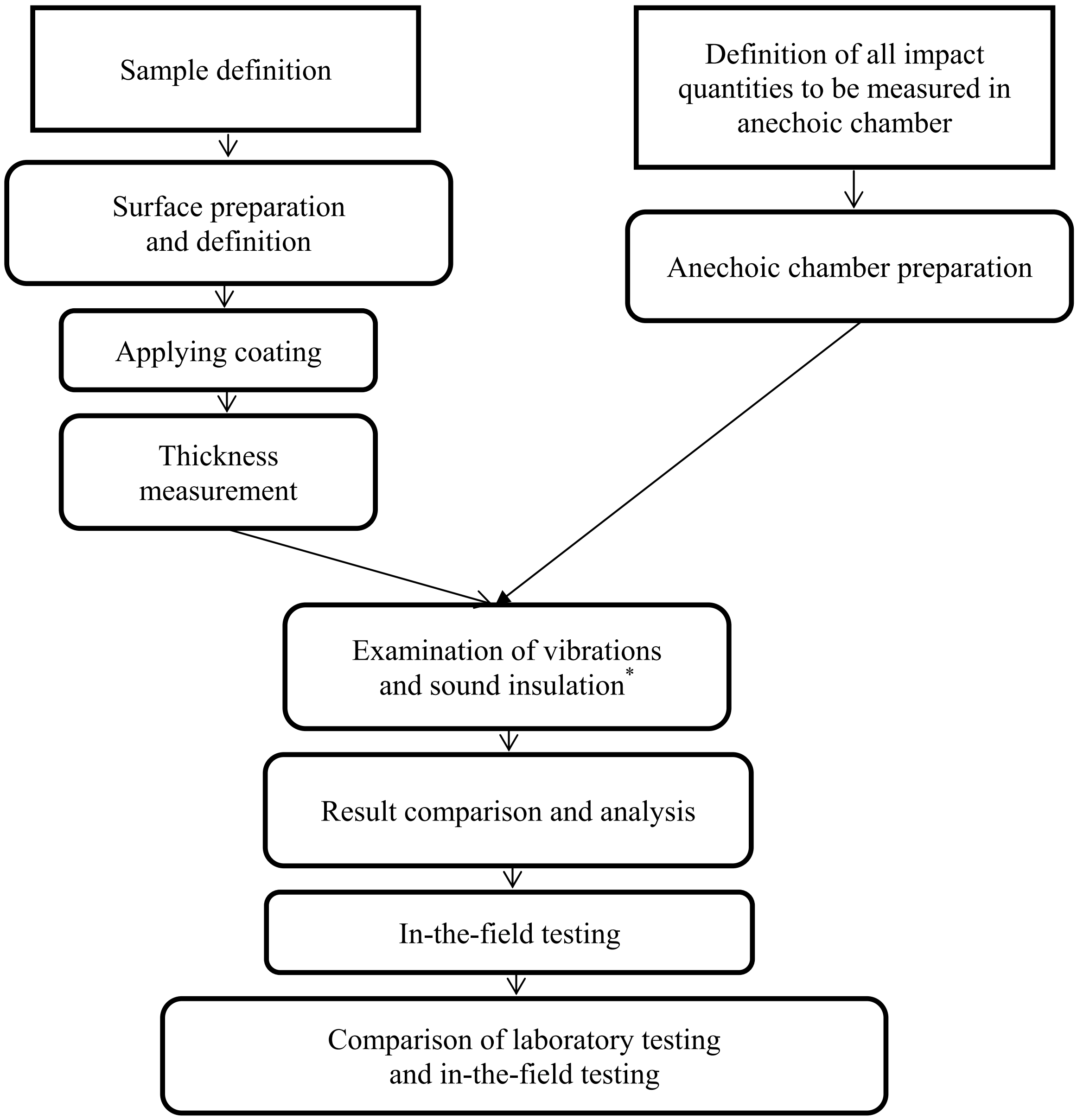
Let us consider in more detail representative exmaples of that development.

Research of Verdejo et al. [10] revealed that acoustic waves can be scattered by interfacial sliding and stick-slip behaviour even in the presence of some covalent bonds. It was also defined that damping effects are attributed to the large surface area at the polymer-carbon nanotube interface. In the experimental study, Rajoria and Jalili [11] found that multi-walled carbon nanotubes present good reinforcement choice for damping enhancement. As a particular result, let us emphasise that up to 700 % enlargening of the damping by epoxy-based coating was observed when weight ratio of multi-walled carbon nanotubes in epoxy was 5,0 %. In their research Ruijgrok et al. [12] studied damping of vibrations in the acoustic region, by the homogeneous water suspension of gold nanospheres (80 nm diameter) and nanorods (25 nm diameter and 60 nm length). Their results indicate that vibrational damping occurs by dissipation of acoustical energy in the liquid and by intrinsic damping of a particle.

In the context of reducing enviromental noise, in particular of the noise emitted by machines such as compressors, vehicle engines etc., it is important to examine vibration and noise damping properties of coatings developed purposefully for listed noise sources. Noise generated by a machine can be reduced by supression of its surface vibrations, covering of wall by acoustically absorbing materials, by shielding (encapsulation) of noise sources, or by a combination of these measures [13]. Generally, examination such as the one presented in Fig. 2 is needed in order to determine the damping characteriscs of a coating.

First, it is important to characterise the sample regarding its shape, dimensions and material characteristics [14]. In accordance with the desired level of noise and vibration damping, the coating material should be determined. Then, the surface preparation takes place, according to sample material and coating to be applied. After surface preparation it is important to define surface by measuring its waviness and roughness in order to make conclusions about properties of e.g. new materials application. The prepared surface are coated with the choosen coating material. Subsequently, thickness of the coating material layer is determined, as it represents a possible factor influencing the coating noise damping characteristics [14]. Prepared sample should be examined in adequately prepared anechoic chamber. In one part of it is the source, in the other the receivers, while the prepared sample is put between them.

Testing of the vibrations and sound insulation in the anechoic chamber is conducted on the samples with coatings as well as on the samples without coating which functions as a referent sample. One expects that in this phase some results are obtaiend that can be utilised in formulating the improvements in coatings, their compositions and textures. In-the-field testing



*measuring surface waviness and roughness

Figure 2. Structure of the testing of the damping characteristics of a coating.

of noise damping system is influenced by many different factors such as is a resonant characteristics of the interior in which the machine is placed. Because of that, in-the-field testing is unavoidable.

ADAPTIVE NOISE PROTECTION

As inferred from Fig 1a, there exists a frequency bandwidth in which the noise reduction by plants is rather small. It is then opportune to purposefully develop coatings which are maximally efficient in vibration reduction in that frequency region. Having in mind that frequency dependence of vibration supression is rather non-trivial, i.e. nonlinear, parameters describing the optimal coating may differ in cases that different frequency bandwidth is used for optimising average noise reduction.

CONCLUSIONS

Noise is a significant contemporary pollutant, in the focus of relevant international and national authorities. Two noise reduction approaches, one based on natural and the other on artificial noise barriers, are discussed, compared, and used as components of novel, adaptive, noise reduction system. The artificial part is realised as nano-level treated materials since they have revealed a significant potential in noise reduction.

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ADAPTIVNI SUSTAV SMANJENJA BUKE

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SAŽETAK

Buka je sveprisutni izvor zagađenja okoline, kojeg se smatra jednim od najvećih današnjih zagađivača. Po cijelom svijetu provode se koordinirane akcije s ciljem razvoja sustava koji minimizira utjecaj buke na društvo.

U ovom članku razmatramo novi pristup potiskivanju utjecaja buke. Nadalje, razmatramo je li učinkovit pristup postavljanju široko primjenjivog, neprimjetnog, adaptivnog sustava zaštite od buke. Ovaj pristup objedinjuje prirodne strukture zaštite od buke temeljene na drveću i umjetno ostvarene prevlake.

Razmatrani su elementi sustava, njegovo postavljanje, održavanje i perspektive primjene.

KLJUČNE RIJEČI

buka, zvuk, gušenje, adaptacija, nanotehnologija