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Noise in small workroom

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ABSTRACT

Sound fields in industrial workrooms can be predicted well using numerical methods. Prediction models can be used in helping to predict the benefits of and to optimize control measures. Two main factors influence the sound propagation in workrooms – the boundary conditions of the room and the fittings in the room. These factors should be accounted for in prediction models. Prediction models are employed to predict the sound fields in the measured configurations. To investigate the propagation of the sound in real workrooms, experiments were performed. The noise, of an omni directional sound source, was measured in many points of the room space simultaneously using a multi channel signal acquisition system. This allowed the comparison of simulated results with the ones measured in real rooms.

INTRODUCING

The noise abatement problems in industrial workrooms result not only from the excessive noise production by the sources – machines and their arrangement, but also from the properties of the whole complex: technological process – machinery – workroom. Workroom is the space enclosed by a fixed arrangement of the walls. Its volume, total walls area, the applied construction and finishing materials and the interior geometry provide the basic data that have to be taken into account in the interior acoustics. The actual conditions of sound wave propagation in closed rooms are characterized by great complexity. It results from the presence of one or more noise sources of various acoustic parameters, the acoustic properties of the room itself and some physical phenomena taking place in the sound wave field. There is a certain class of phenomena taking place in the examined room, that can be learned with only one sound source and one (or more) observation points [1]. Registering the sound in a single point of the room, one knows that it results from a superposition of many sound waves. They have reached the point as a result of one or more reflections from the interior walls, but in addition there is also a direct wave, that has arrived along the shortest path between the source and the observation point. During reflection of acoustic wave from a surface its energy is partially absorbed and its phase angle is subject to a change (phase-shift) related to the acoustic impedance of the wall. Acoustic wave reflected from a rough surface is also subject to dispersion. The contributing phenomena produce the sound reaching the observation point, in which all the information concerning the properties of the room are contained, both of general nature (global properties of the room) as well as particular features (concerning the essential pair of points: source – observation point). There is a widely applied procedure called acoustic modeling of the room. Employing the room model includes the interpretation of knowledge and measurements obtained from previous observations for obtaining new information concerning the examined object. Greatest amount of information concerning the room properties is included in the impulse response, therefore in most measurement methods presently applied the room response function is measured and from its properties all the necessary parameters are calculated [3].

MODEL OF SOUND TRANSMISSION IN THE ROOM

An important issue is the selection of such a model for the system consisting of source (control) – acoustic object – acoustic field parameters (system response), which will be the most useful in the simulation studies. In a simplified model the room is presented as a system with constant parameters, in which two special points are selected: sound source point and observation point. The properties of a linear system can be described by an impulse response (system response to Dirac or Kronecker delta stimulus), which is an inverse Fourier transformed of the spectral transmittance. The impulse response contains the description of series of modifications, that the acoustic signal undergoes on its way from one point to another point in the sound field.

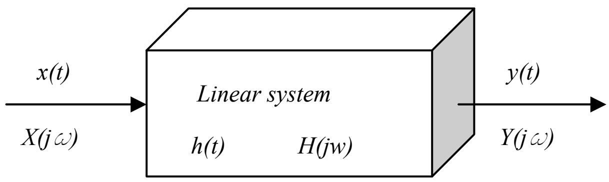

Figure 1. Model of the room sound transmission system

where: *h(t)* – impulse response in the time dependent form, *H(jω)* – spectral transmittance of the linear system, *x(t)* –

input signal in the time dependent form, $X(j\omega)$ – spectral form of the input signal, $y(t)$ – output signal in the time dependent form, $Y(j\omega)$ – spectral form of the output signal.

If the transmission path of the sound is presented as linear system with one input (as in Fig.1) then the signal at the output of a stationary linear system is a convolution (*) of two functions – the input signal and the impulse response (1)

$$y(t) = h(t) * x(t) = \int_{-\infty}^{\infty} h(\tau)x(t-\tau)d\tau \quad (1)$$

The $h(t)$ function is the impulse response of the system, dependent on the positions of the sound source and the observation point. It is the system response function value in a given time t, after a Dirac delta function δ stimulation applied in time $(t-\tau)$.

If one is interested in evaluation of phenomena taking place in the room in the frequency domain then the spectral transmittance $H(j\omega)$ can be used.

$$\boldsymbol{Y(j\omega) = H(j\omega)\, X(j\omega)} \quad (2)$$

where $H(j\omega)$ transmittance function is a Fourier transform of the impulse response $h(t)$

$$H(j\omega) = F(h(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} h(t)e^{-j\omega t}dt \quad (3)$$

while

$$X(j\omega) = F(h(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} x(t)e^{-j\omega t}dt \quad (4)$$

$$Y(j\omega) = F(h(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} y(t)e^{-j\omega t}dt \quad (5)$$

are Fourier transforms of the $x(t)$ and $y(t)$ signals.

Knowing the transmittance function $H(j\omega)$ of the system one can always determine its impulse response [3, 6].

EXPERIMENTAL STUDIES

If the source and reception point locations are specified in the room the relation between the sound pressures in both points takes the form of a convolution

$$\boldsymbol{p_r(t)=h(t)*p_s(t)} \quad (6)$$

where $p_r(t)$ – sound pressure at the receiver point, $p_s(t)$ – sound pressure at the source point, $h(t)$ is the impulse response of the room.

The experimental studies have been carried out in a small industrial type room (see Figure 2) of the dimensions 6,7 m x 3,9 m x 2,86 m and total volume 74,5 m^3. The room was empty, the floor has been laid-out with terracotta tiles, the walls and the ceiling have been plastered (smooth plaster upon a brick wall), and one of the walls contained a varnished hardboard door. The measurement system used for determination of the acoustic characteristics of the room has been shown in Figure 3.

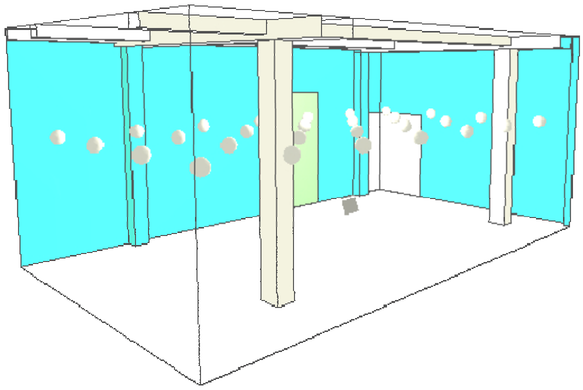

Figure 2. View of the examined room

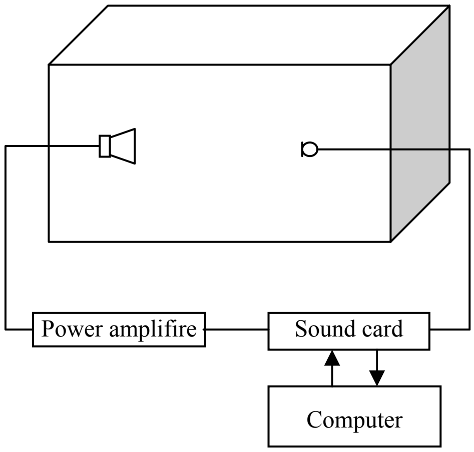

Figure 3. Block-diagram of the measurement setup

The impulse responses have been obtained using the MLS method and software package called DIRAC Room Acoustics Software (Figure 4). Pseudo-random MLS signal measured in the reception point is correlated with the original input signal sequence. As a result of this cross correlation the impulse response of the system is obtained. When full information concerning the time characteristics of the system is available, the frequency characteristics can be calculated using the Fourier transform.

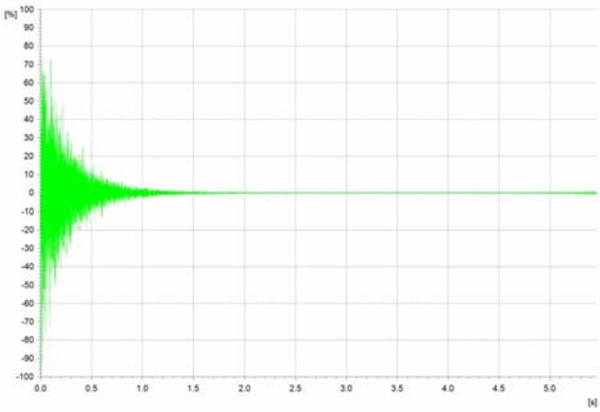

Figure 4. An exemplary impulse response of the room

The impulse responses of the room have been determined in reception points evenly spaced on a measurement grid. From the registered signal all the acoustic parameters have been obtained, which can be calculated using the Dirac software package, namely EDT, T10, T20 and T30 reverberation times, strength G, magnitude, STI and others: energy ratios and speech intelligibility parameters. Figure 5 and Table 1 present the averaged values of RT and EDT for individual octave frequency bands.

Table 1. Reverberation time EDT, RT20, RT30, RT

f, Hz	63	125	250	500	1k	2k	4k	8k
EDT	4.7	3.4	3.2	2.1	1.8	1.9	1.7	1.3
RT20	5.9	3.6	3.3	2.2	1.8	1.9	1.7	1.3
RT30	5.9	3.6	3.4	2.3	1.8	1.9	1.7	1.3
RT	5.6	3.6	3.4	2.2	1.8	1.9	1.7	1.3

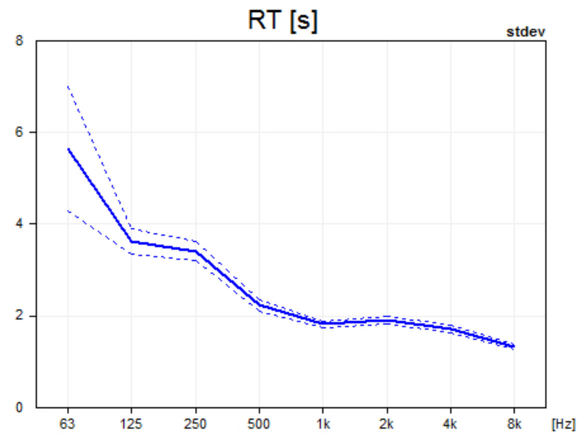

Figure 5. Spatially averaged RT reverberation time results (28 observation points) (--- standard deviation of the reverberation time)

Next stage in the studies of the room's acoustic properties comprised the measurements of uneven distribution of the sound level values in the enclosed space. In 28 measurement points (P01 to P28) many acoustic parameters have been measured, like acoustic pressure levels in third-octave and one-octave frequency bands, sound levels with A, C and LIN frequency correction filters. Using these measurement results acoustic maps have been plotted for distributions of acoustic pressure levels in octave frequency bands. The distributions of the sound pressure levels have been registered for three different locations of an omni directional sound source: in the center of the room, in one of the corners, and in the middle of the longer wall. The results of these measurements have been presented in the form of acoustic maps for selected octave frequencies 125 and 500 Hz (see Figure 6).

ACOUSTIC PARAMETERS OF THE ROOM

Distribution of the sound field can be controlled by changing values of the following quantities: properties of the medium, locations of the sound sources, properties of the sound sources, boundary conditions and geometry of the examined space, in which the acoustic wave propagates. The control over some of the quantities, e.g. properties of the media in which the acoustic wave propagates, is rather difficult, but there are also quantities the values of which can be easily changed e.g. the properties of sound sources or acoustic conditions at the space boundary. For calculation purposes a three-dimensional geometrical model of the room has been created. The computer simulation has been carried out using the Raynoise software package, dedicated to sound field analysis. It employs geometrical methods, in particular the cones method, for modeling of the examined 3D space. It predicts the sound propagation in the room, taking into account the applied distribution of sound sources. Each individual sound source is defined by its spectrum of sound power and directivity characteristics [8, 9]. In the calculations multiple reflections are taken into account, from various surfaces with their respective sound absorption coefficients. The modeling results can be presented in many ways: starting from third-octave band spectra and echograms to full colored SPL maps. The software allows modifications of the model's acoustic parameters. The calculations have been carried out for the whole available frequency band i.e. for octave frequencies from 63 Hz to 8000 Hz.

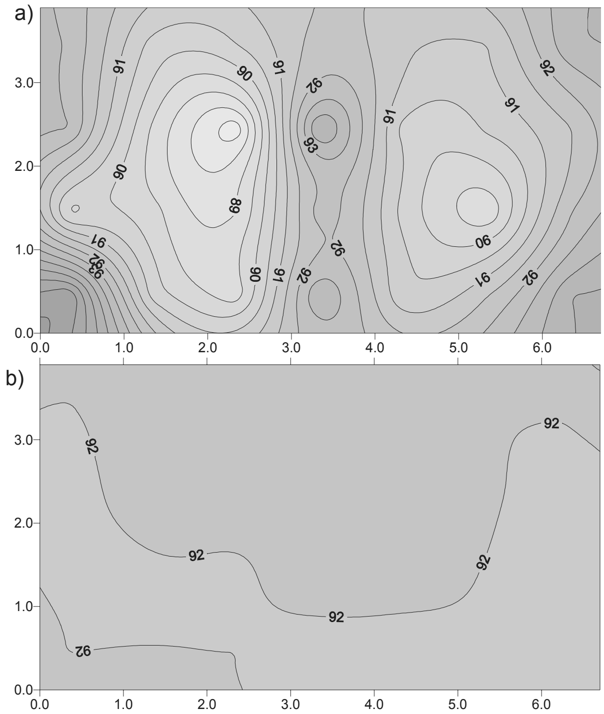

Figure 6. Distribution of sound pressure levels for 125 Hz frequency a) measurement b) calculation

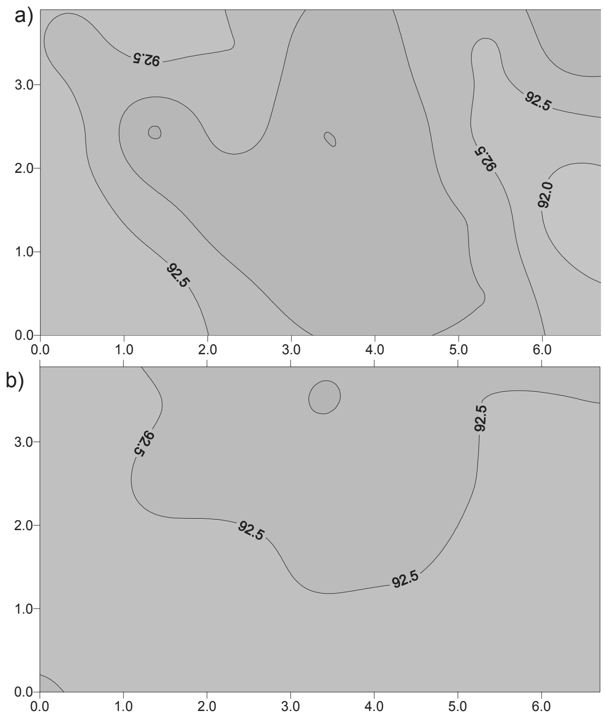

Figure 7. Distribution of sound pressure levels for 500 Hz frequency a) measurement b) calculation

The comparison of the constant sound pressure level lines in Fig.6 shows, that for the lower frequencies the geometrical method of sound pressure level determination in a small room exhibits considerable deviations from the measured values. Figure 8 presents the effect of the room properties on the sound propagation from various positions of the sound source, keeping its acoustic power as constant. For the examined room the calculated Schroeder limit frequency f_{min} is equal to 340 Hz [11]. In the lower frequency range the sound field modeling should be rather done using the wave propagation methods. In our problem an essential element is the knowledge of boundary conditions at the walls of the examined space. Important boundary parameters of the examined space are the absorption properties and the acoustic impedance values of the material applied at the wall surfaces. Therefore collecting the information concerning the boundary conditions of the room is a key factor in the modeling of sound field parameters.

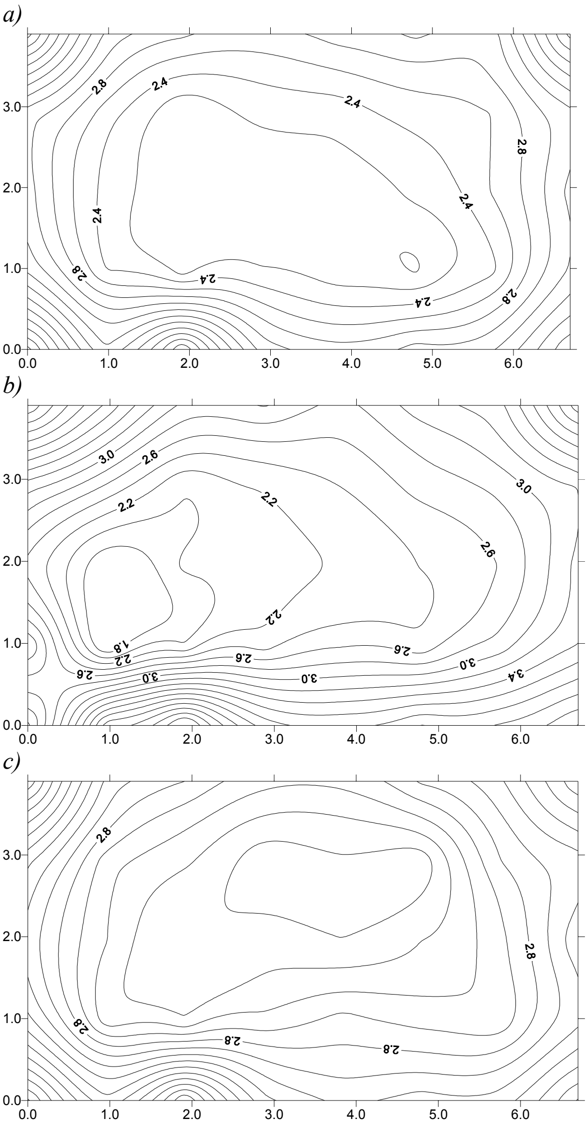

Figure 8. Effect of the room on the sound field distribution
a) sound source at the middle of the tested room
b) sound source at the left corner of the room
c) sound source in the centre of the wall

During measurements in the room a wide range of experimental research has been carried out in order to compare the modeling and experimental results. It was also related to the problem of uncertainty evaluation for experimental determinations of many parameters. The next step in the study was the modification of the room arrangement and determination of the effect of individual actions on the parameters of the sound field distribution. The knowledge of the acoustic parameters of the room offers a possibility of predicting the sound field created by a machine (machines) of specific acoustic characteristics, located within this room. The examined room, from the acoustic point of view, should be treated as a small one in the wave aspect: the wavelength and the room dimensions are in the same order of magnitudes, i.e. they differ by a factor between one and ten. A characteristic features of such rooms is the clearly noticeable presence of wave phenomena i.e. the superposition, dispersion and diffraction of waves. Proper description of the sound field requires including all the phase relations in the model of medium particles vibrations.

All the described actions are oriented towards ensuring a comforting acoustic climate at the working posts and in the whole work environment, and in the extreme cases ensuring that the actual values do not exceed the allowable values in the places where the working persons stay during their working hours.

SUMMARY

Impulse response of the room allows determining its acoustic properties and the effect that the room may have on the created and propagated acoustic signal. The problem of the distribution of sound field parameters in small rooms dedicated to workshop functions is mostly related to the low frequency vibrations. The geometrical methods are dedicated to medium and high frequencies. The presented experimental example indicated the correctness of model solutions for the examined room (geometric methods) for frequencies above 340 Hz. Because of the size (volume) and low values of the absorption coefficients at the walls, ceiling and the floor the sound fields in the room are of diffusive nature. The experimentally determined reverberation times exhibit essential discrepancies for frequencies below 340 Hz. For this frequency range the solution should be looked for in application of finite or boundary element methods, what requires the knowledge of acoustic properties of the enclosing surfaces. One can also look for the dependence of the acoustic system transmittance on the surface acoustic impedance, describing the boundary conditions of the room. The specific acoustic properties of the materials applied in the model studies are usually determined in the laboratory conditions. They are often different from the values determined in-situ [2, 5], what requires further elaboration of measurement methods for acoustic parameters of materials in actual conditions.

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