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Investigation and application of theoretical acoustic field model evaluating the change of environmental conditions

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The effectiveness of the means used to reduce the noise depends on many factors. One of the main factors is the sources which generate acoustic field. Therefore the task of the creation of the mobile noise reduction means, their rational arrangement and control becomes more and more relevant. In this case theoretical modeling of interaction of acoustic noise control systems with environment has significant importance for creating such systems. This paper provides acoustic field model using FEM, which imitates changing conditions of real industrial premise, evaluates the effectiveness and application possibilities of the mobile noise reduction system. The results showed that with the help of the model mobile noise reduction system can be modeled, their effectiveness might be evaluated considering the change of sources and reflection planes, and the structural model of the investigative room can be supplemented with acoustic noise reduction means – noise reduction screens, selecting their geometric dimensions, arrangement in the space and predicting the values of acoustic field parameters in the real object point under consideration.

1 Introduction

The effectiveness of the tools used to reduce the noise depends on a number of factors, first of all including the sources, which create the acoustic field. There are a lot of sources in the industrial premises, they have different affects on the field, and they can change when the environmental conditions are changing. Thus the task to create the mobile tools reducing the acoustic noise, to arrange them rationally, and to manage them is becoming more and more topical. When the management systems of the acoustic noises are being created, the theoretical modeling of their interaction with the environment cannot be avoided.

One of the widely used methods to create the acoustic models is the method of finite elements. When this method is used (as well as when the method of finite differences is used), the wave equation is being solved (with regard to the boundary conditions) by dividing the space (in certain cases the time, too) into the elements. Then the wave equation is expressed by the discrete set of the linear equations for these elements. The method of the finite elements also allows modelling the energetic transmission between the separate surfaces (funk-beam tracing). The advantage of this method [1, 2, 3] is that it allows linking directly the structural and acoustic media and evaluating their interaction under changing conditions of the modelled environment, which is extremely important for creation of the systems of acoustic partitions. The results received with the help of this method while solving the three-dimensional tasks of the acoustic medium reflect completely the character of the acoustic field in the analyzed space. This makes a certain basis for the modelling of acoustic fields [4]. However the modelling of the acoustic field characterized by the heterogeneity and generated by various sources in the closed room with the different acoustic characteristics needs additional investigations.

In order to reduce the acoustic noise in the passive mode by the mobile screens, the following tasks have to be solved:

- To create the model of the acoustic field in the closed space on the basis of FEM evaluating the change of environmental conditions;
- To analyze the adequacy of this theoretical model for the real fields and application possibilities while projecting the mobile or controlled noise reduction systems.

2 Model of acoustic field on the basis of FEM

The discrete acoustic wave equation that evaluates the interaction with the structural medium and losses in case of collision with it is expressed in the following way in the formula of finite elements:

$$\left[M_e^P\right]\{\ddot{P}_e\}+\left[C_e^P\right]\{\dot{P}_e\}+\left[K_e^P\right]\{P_e\}+\rho_0\left[R_e\right]^T\{\ddot{u}_e\}=0 \qquad (1)$$

In order to describe fully the interaction of the acoustic medium and structure, the affect of pressure on structure has to be evaluated. In such a way the main structural dynamic equation is the following:

$$\left[M_e\right]\{\ddot{u}_e\}+\left[C_e\right]\{\dot{u}_e\}+\left[K_e\right]\{u_e\}-\left[R_e\right]\{P_e\}=\{F_e\} \qquad (2)$$

where: $\left[M_e^P\right]$, $\left[M_e\right]$ matrixes of the mass of acoustic medium and structure, accordingly,

$\left[C_e^P\right]$, $\left[C_e\right]$ damping matrixes of the acoustic medium and structure,

$\left[K_e^P\right]$, $\left[K_e\right]$ stiffness matrixes of the acoustic medium and structure,

$\rho_0\left[R_e\right]^T$ matrix of the connection between acoustic and structural media,

$\{P_e\}$ vectors of the pressure in nodes and its derivatives with regard to time $\{\dot{P}_e\}$, $\{\ddot{P}_e\}$,

$\{\ddot{u}_e\}$ vector of the derivative of the nodal displacement,

$\{F_e\}$ vector of load,

ρ_0 density of air medium.

The joined equations (1) and (2) describe completely the interaction of the structure and acoustic medium and are expressed in the following way in the formula of finite elements:

$$\begin{bmatrix}[M_e] & [0]\\ \rho_0[R_e]^T & [M_e^P]\end{bmatrix}\begin{Bmatrix}\{\ddot{u}_e\}\\ \{\ddot{P}_e\}\end{Bmatrix}+\begin{bmatrix}[C_e] & [0]\\ [0] & [C_e^P]\end{bmatrix}\begin{Bmatrix}\{\dot{u}_e\}\\ \{\dot{P}_e\}\end{Bmatrix}+\dots$$
$$+\begin{bmatrix}[K_e] & -[R_e]\\ [0] & [K_e^P]\end{bmatrix}\begin{Bmatrix}\{u_e\}\\ \{P_e\}\end{Bmatrix}=\begin{Bmatrix}\{F_e\}\\ \{0\}\end{Bmatrix} \qquad (3)$$

When the theoretical model is formed, the FEM software ANSYS 10 was used. The analyzed two-dimensional model consists of the acoustic and structural media. In order to model them the elements FLUID29 and PLANE42 were used. While modeling the harmonious analysis was made, when the system was harmonically excited by two sources of certain pressure. The excitation frequency, acoustic partition walls, absorption coefficients of the premise's ceiling were changed during the analysis and the acoustic homogeneous and non-homogeneous field were analyzed. The received results of the theoretical experiment are presented below.

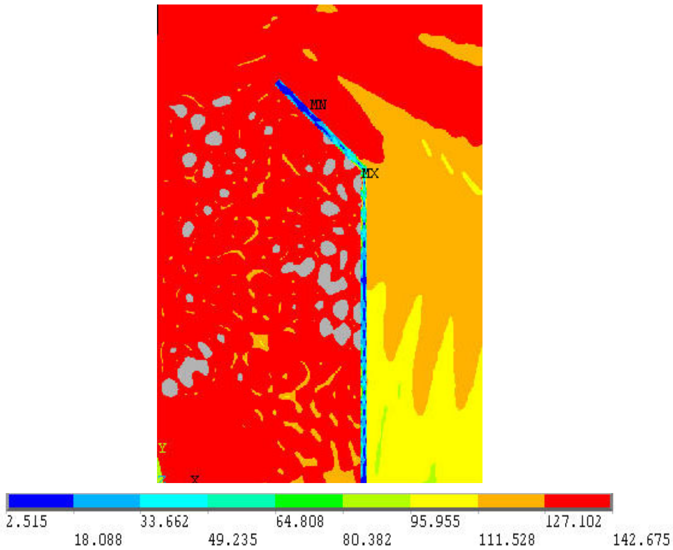

Fig. 1 Level of acoustic pressure in the non-homogeneous field, when the excitation is done by two sources of different frequency: L_{p1}=125 dB, f_1=1000 Hz, L_{p2}=97 dB, f_2=100 Hz, sound absorption coefficient of the partition wall μ=0.2, ceiling's absorption coefficient μ=0.1.

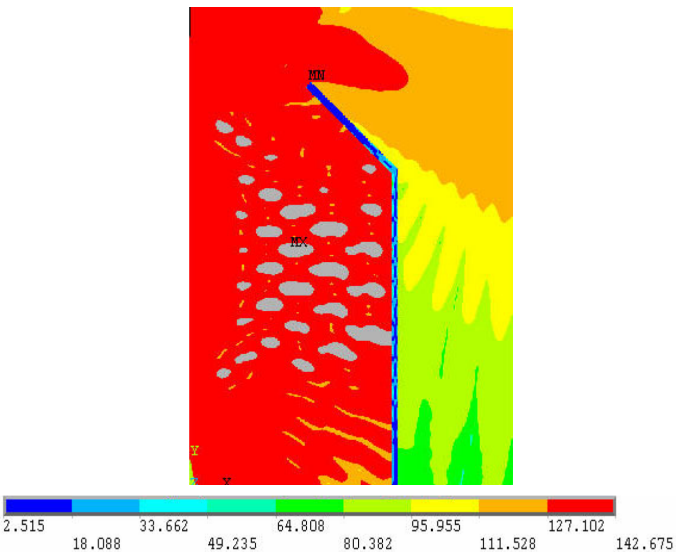

Fig. 2 Level of acoustic pressure in the non-homogeneous field, when the excitation is done by two sources of different frequency: L_{p1}=125 dB, f_1=1000 Hz, L_{p2}=97 dB, f_2=100 Hz, sound absorption coefficient of the partition wall μ=0.2, ceiling's absorption coefficient μ=0.9.

The distance from the excitation source to the partition wall was 2 m. The physical characteristics of the separate model's elements were the following: air density ρ=1.2 kg/m^3; velocity of acoustic wave's spreading c=335 m/s; absorption coefficient of air sound μ=0; density of the partition ρ=950 kg/m^3; elasticity module of the partition E=2.3e+9 Pa; speed of sound's spreading in the partition substance c_p=1700 m/s; sound absorption coefficient of the partition μ=0.1-0.9.

During the transient analysis there was modelled the noise that occurs during the exploitation of a pneumatic press, i.e. there was imitated the punch stroke onto the press form, and the alteration of the sound pressure, induced by this phenomenon in the acoustic environment. The received results of the theoretical experiment are presented below.

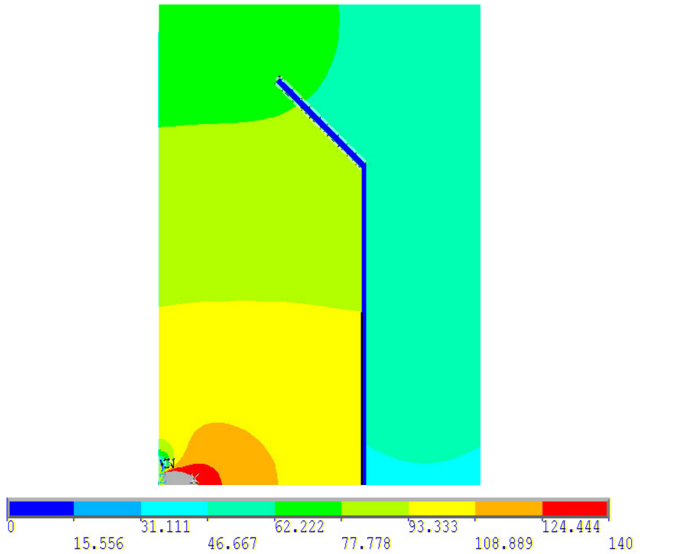

Fig. 3 Acoustic pressure during impact in non-homogenous field (partition wall present)

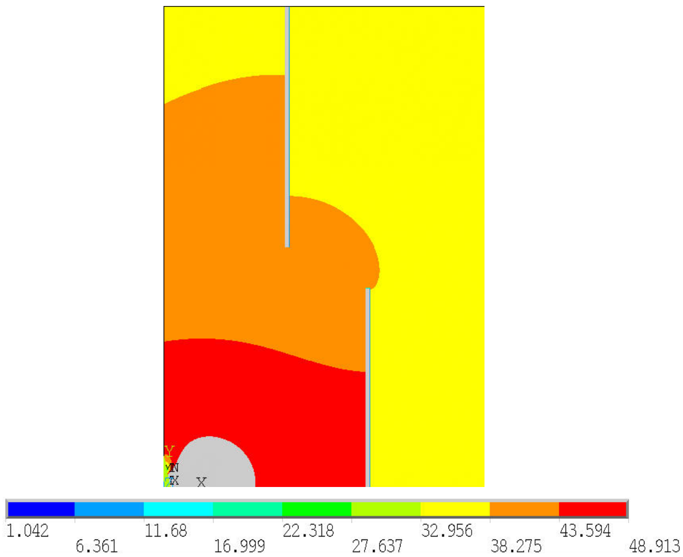

Fig. 4 Acoustic pressure during impact in non-homogenous field (two partition walls present)

That was assumed that impact of punch onto the press form is perfectly elastic, maximal power of pneumatic press P=160 kN. The physical characteristics of the punch were the following: density ρ=7800 kg/m^3; elasticity module E=2.3e+9 Pa; speed of sound's spreading in the partition of the punch c_p=4003 m/s; Poisson's ratio ν=0.3.

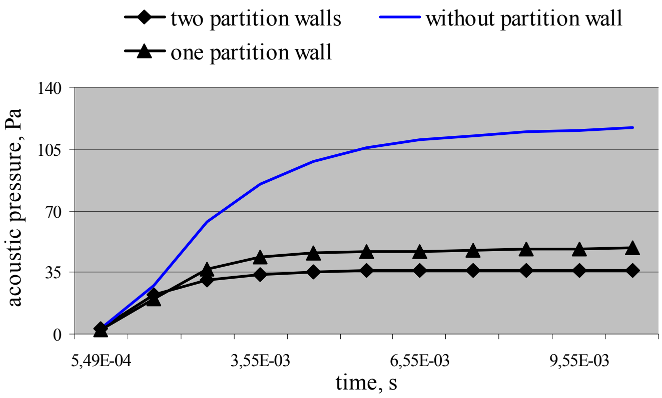

Fig. 5 Acoustic pressure at the distance of 3.2 m from a pneumatic press and in the height of 1.5 m.

The presented calculation results show that the level of acoustic pressure in the homogeneous and non-homogeneous acoustic fields under similar excitation conditions is different In the praxis it often happens that there exist more than one excitation source the frequencies of those are different. There are also enterprises in those the induced noise is of impulse (impact) pattern. The figures 1-2 present the results of the theoretical calculation in case the excitation is done by two sources of different frequency and acoustic pressure. According to the received results, the level of acoustic field's pressure also changes in this case when the frequency of one source is low, and the other's is high, and the parameters of the reflection planes are changed. In figures 3, 4, there can be seen the pressure distribution of the acoustic sound as well as the scope in the presence of impact excitation in a non-homogenous field. In the figure 5, there is presented the dependence of the sound pressure during impact in the point that is in 3.2 m distance from the pneumatic press in the height of 1.5 m, in the presence of different count of the partition walls.

To summarize, it is possible to state that the created theoretical model on the basis of FEM defines the size and character of the pressure's level in the acoustic medium in any point of homogeneous and non-homogeneous field, as well as when the characteristics of reflection planes, excitation frequencies and pattern are changed.

3 The experimental research of a theoretical model

In order to analyze the effectiveness of the created theoretical model, the experimental test was done and the received results of the theoretical modelling were compared to the experimental ones. The initial data of the theoretical experiment were selected through the imitation of the real experiment, which was done by company "SAPA Profiliai", where in order to reduce the acoustic noise the workshop of the pipe cutting used the acoustic partition walls. Figure 6 shows the general view of this mounted partition wall. In the real object the noise that appears while cutting the pipes was measured, and its spectral analysis was done using the measurement equipment "Pulse" of the company Bruel & Kjaer. According to the received range of acoustic pressure's level, five dominant frequencies were distinguished, which values are presented in Table 1:

Frequency, Hz	400	1250	3150	6300	8000
Level of acoustic pressure, dB	70,43	80,04	97,05	102,37	97,77

Table 1 Excitation frequencies and their values

During the experiment the values of the acoustic pressure were measured behind the partition wall in the height of 1.5 m.

Fig. 6 General view of the acoustic partition wall in the workshop of aluminium pipe cutting

In order to do the theoretical analysis of the acoustic noises in the pipe-cutting workshop, the above-described method on the basis of FEM was used together with the harmonious analysis, during which the excitation was done harmonically by the determined values of the acoustic pressure corresponding to certain excitation frequency. The received results of the theoretical and experimental tests are presented below.

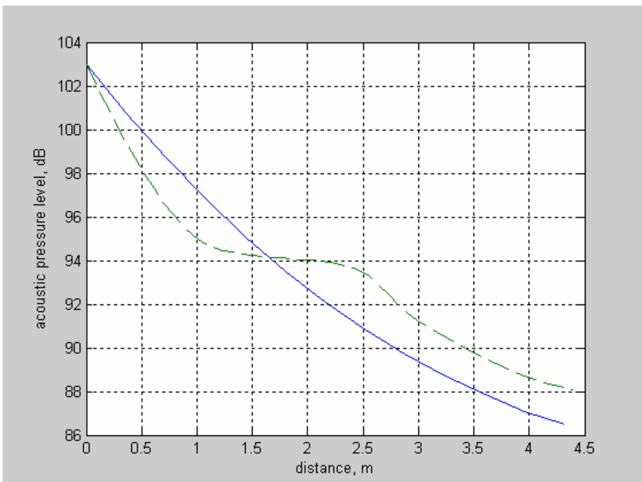

Fig. 7 Dependency of the acoustic pressure's level on the distance to the acoustic partition wall: ▬▬ approximated

experimental curve,– – – the curve received with the help of theoretical model

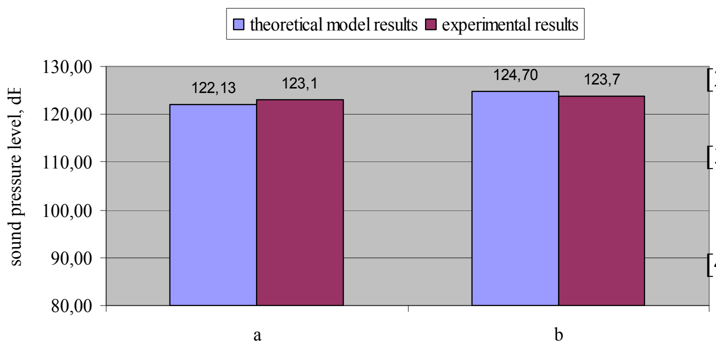

Fig. 8 Level of acoustic pressure in the point of 1.5 m height: a) at the distance of 3.2 m from a pneumatic press; b) directly at work place of a pneumatic press

When the acoustic excitation was imitated, which appears in real operation conditions, the theoretical model helped to determine the distribution of the acoustic pressure in the area of cutting machine. The dependencies of the acoustic pressure on the distance to the partition wall (Fig. 7) and sound pressure level in case of impact (Fig. 8) received with the help of theoretical and experimental models show quite good correspondence of the results.

To summarize, it is possible to state that using the theoretical model created on the basis of FEM it is possible to model the acoustic excitation that appears in real conditions and to evaluate the effectiveness of the mobile system suppressing the noise.

4 Conclusion

The received results of the numeral experiment show that the suggested theoretical model created on the basis of FEM is adequate to the real processes registered in the industrial premises. The model allows modelling mobile noise suppression systems and evaluating their effectiveness with regard to the changes of sources, reflection planes and the pattern of the excitation.

When the passive method of noise suppression is implemented in the industrial or other premises, the theoretical model will allow supplementing the structural model of the analyzed premise with the reduction equipment of acoustic noise – noise suppression screens, selecting their geometrical parameters, arrangement in space, and substances, in order to gain the maximal noise reduction and to predict the values of the acoustic field's parameters in the analyzed point of the real object after the environmental conditions have changed.

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