ISSN 1392 - 1207. MECHANIKA. 2009. Nr.2(76)

Investigation of adequacy of the acoustical field model

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1. Introduction

The noise in the industrial companies is caused while operating the mechanisms and equipment and during various technological operations. The effect of these excitation sources on the acoustic field is very different and the formation mechanism of the generated noise is very complex. Many models are used for investigation of acoustic fields. Simplified analytical models [1] allow us, on the base of calculus of variations, to determine the reaction of different structures to the shock pulse load, including and acoustic pressure load [2]. But these models not so easy to apply for real practical tasks, because their preconditions (among them very often free boundary conditions are chosen or conditions which is not identified by the real situation and parameters). Therefore in order to reduce the noise effectively in various technical environments using the passive method, the modelling of the interaction of real object with the acoustic medium is necessary.

One of the widely used methods to create the acoustic models is the finite element method (FEM). When this method is used (as well as when the method of final 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 linear equations for these elements. FEM also allows modelling energy transmission between the separate surfaces (funk-beam tracing). The advantage of this method [3-5] is that it allows linking directly structural and acoustic media and evaluating their interaction under changing conditions of the modelled environment, which is extremely important for the creation of the systems of acoustic partitions. The results obtained with the help of this method while solving the three-dimensional tasks of the acoustic medium reflect completely the character of acoustic field in the analyzed space. This makes a certain basis for the modelling of acoustic fields [6]. However the modelling of the acoustic field characterized by the heterogeneity and generated by various sources in a closed room with different acoustic characteristics needs additional investigations.

This work used 2D model to analyze the possibility to model several excitation sources acting at the same time in different harmonic frequencies. The obtained results of the theoretical experiment were compared to the results of practical experiment. The adequacy of the acoustic field's model formed on the basis of the finite elements to the real acoustic field was analyzed.

2. Model of acoustic field on the basis of FEM

The interaction of the structure and acoustic medium are expressed in the following way in the formula of finite elements [7]

$$\begin{bmatrix} [M_e] & [0] \\ \rho_0[R_e]^T & [M_e^P] \end{bmatrix} \begin{Bmatrix} \{\ddot{u}_e\} \\ \{\ddot{P}_e\} \end{Bmatrix} + \begin{bmatrix} [C_e] & [0] \\ [0] & [C_e^P] \end{bmatrix} \begin{Bmatrix} \{\dot{u}_e\} \\ \{\dot{P}_e\} \end{Bmatrix} + \begin{bmatrix} [K_e] & -[R_e] \\ [0] & [K_e^P] \end{bmatrix} \begin{Bmatrix} \{u_e\} \\ \{P_e\} \end{Bmatrix} = \begin{Bmatrix} \{F_e\} \\ \{0\} \end{Bmatrix} \quad (1)$$

where $[M_e^P]$, $[M_e]$ are matrixes of the mass of acoustic medium and structure accordingly; $[C_e^P]$, $[C_e]$ are damping matrixes of the acoustic medium and structure; $[K_e^P]$, $[K_e]$ are stiffness matrixes of the acoustic medium and structure; $\rho_0[R_e]^T$ is matrix of relation between the acoustic and structural media; $\{P_e\}$ is vector of pressure in the nodes and its derivatives with regard to time $\{\dot{P}_e\}$, $\{\ddot{P}_e\}$; $\{u_e\}$ is vector of nodal displacement and its derivatives with regard to time $\{\dot{u}_e\}$ $\{\ddot{u}_e\}$; $\{F_e\}$ is vector of load; ρ_0 is density of air medium.

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. During modelling the harmonic analysis was performed. The noise sources in this work were modelled in the middle frequency range, i.e. in the area, to which the majority of operated industrial machines and equipment belongs and which is very typical in the machine acoustics. As the room of simple form was chosen as the prototype of the theoretical model (the 200 m^3 acoustic chamber of the testing laboratory of machine vibrations and acoustic noises of Technological Systems Diagnostics Institute), the method of dotted sources was used to model the noise sources. This method is simple and easy to apply [8]. Two excitation sources with corresponding frequencies of 1000 and 2000 Hz were used.

While modelling the harmonic response analysis was made, when the system was harmonically excited by two sources of certain pressure and the acoustic homogeneous and nonhomogeneous field was analyzed. The values of acoustic characteristics of walls, ceiling, floors and screens used for the model were taken from the corresponding documentations of the manufacturers. The obtained results of the theoretical experiment are presented below.

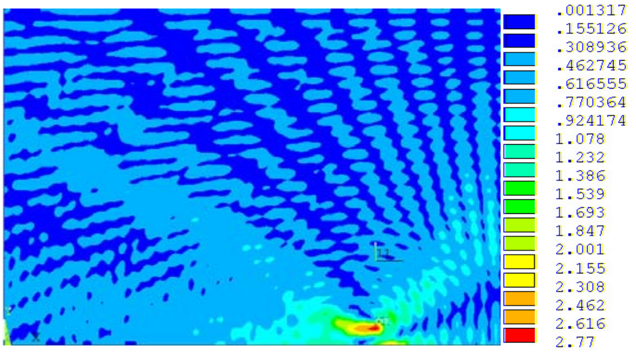

Fig. 1 The sound pressure in the homogeneous acoustic environment when 1000 Hz frequency excitation is used

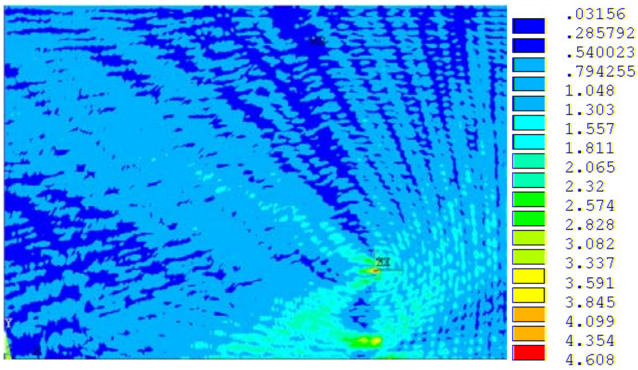

Fig. 3 The sound pressure in the homogeneous acoustic environment when the frequencies of 1000 Hz and 2000 Hz are used to excite at the same time

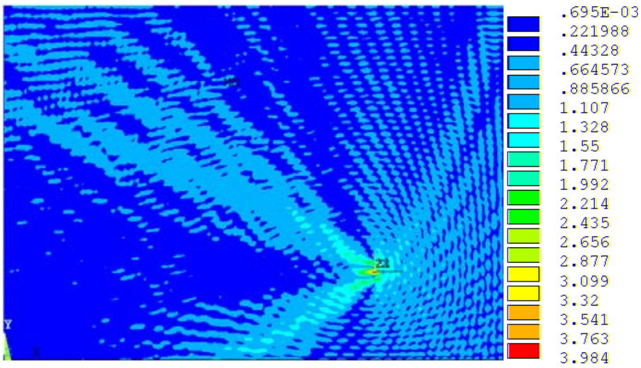

Fig. 2 The sound pressure in the homogeneous acoustic environment when 2000 Hz frequency excitation is used

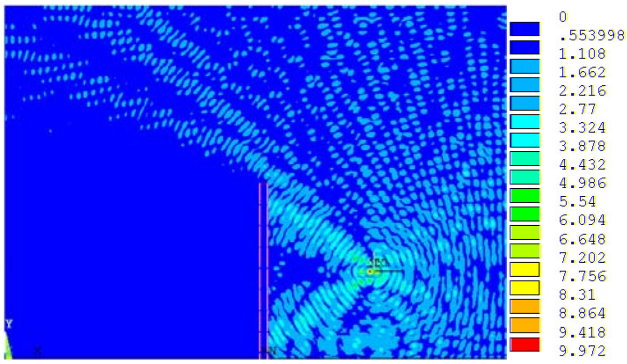

Fig. 4 The sound pressure in the non-homogeneous acoustic environment with screen when 2000 Hz excitation frequency is used

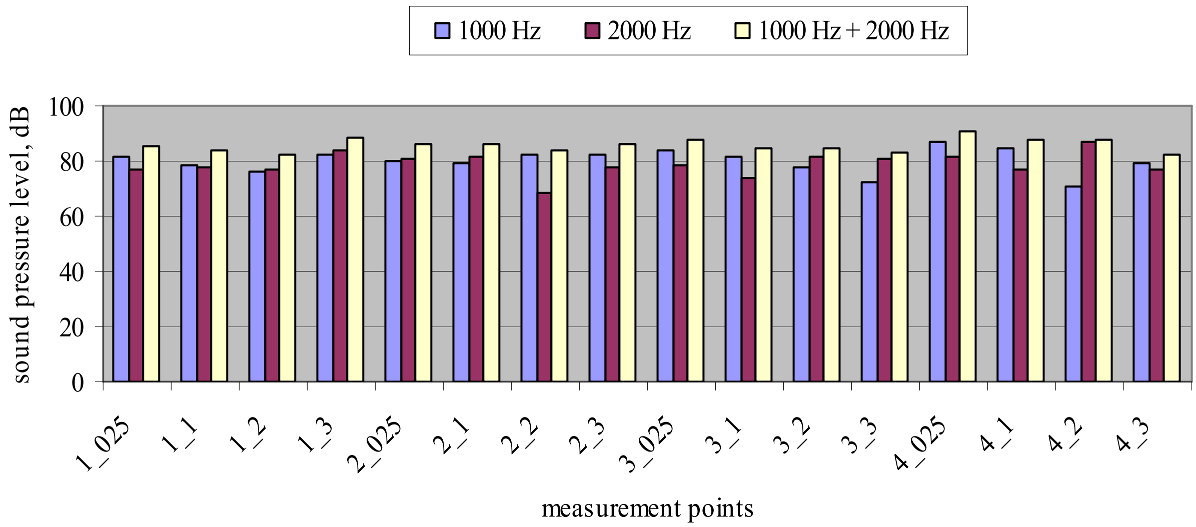

Fig. 5 Values of general level of sound pressure in separate measurement points when excitation pattern differs

The distance from the excitation sources to the partition wall was 0.5 m. Physical characteristics of the separate elements of the model were the following: air density $\rho = 1.2$ kg/m^3; velocity of acoustic wave's spreading $c = 335$ m/s; absorption coefficient of air sound $\mu = 0$; density of the partition $\rho = 950$ 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 $\mu = 0.7$.

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 practice it often happens that there exist more than one excitation source the frequencies of which are different. The Figs. 1-3 present the results of the theoretical calculation in case the excitation is done by two sources of different frequency. According to the obtained results, the acoustic field pressure also changes in this case when the frequency of one source is 1000 Hz, and the other's is 2000 Hz. In Fig. 4 the pressure distribution of the acoustic sound in a non-homogenous field when the partition wall is present can be seen. The values presented in Fig. 5 are the values of general level of sound pressure in separate measurement points. The place of points is shown in Fig. 7.

To summarize, it is possible to state that the created theoretical model on the basis of FEM defines the size and character of pressure level in the acoustic medium at any point of homogeneous and nonhomogeneous field when excited by two sources at the same time.

3. Experimental research of a theoretic model adequacy

In order to analyze the adequacy of the created theoretical model, the experimental test was done and the obtained 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, where in order to reduce the acoustic noise the acoustic partition wall was used. Fig. 6 shows the general view of this mounted partition wall and acoustic sources. During the experiment the values of the acoustic pressure were measured behind the partition wall in particular points. The principal scheme of the measurement experiment of acoustic pressure is presented in Fig. 7.

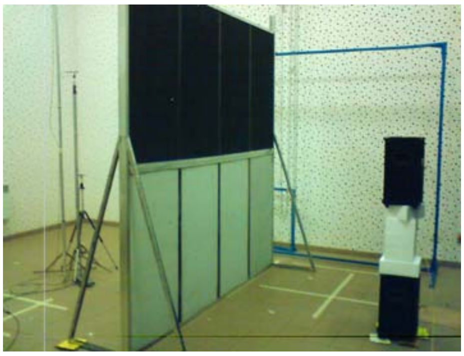

Fig. 6 General view of the acoustic partition wall and acoustic sources in the laboratory

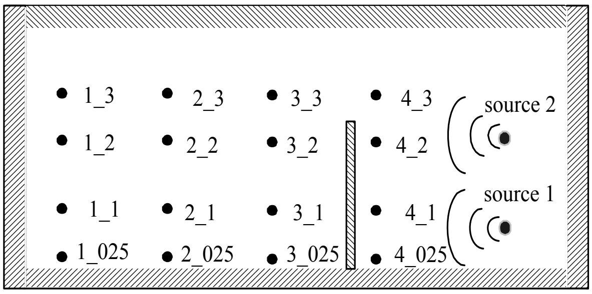

Fig. 7 The principal scheme of the acoustic pressure measurement

In order to do theoretical analysis of the acoustic noises in the testing laboratory, the above-described method on the basis of FEM was used together with the harmonic analysis, during which the excitation was done harmonically by the determined values of the acoustic pressure corresponding to certain excitation frequency. The acoustical field was produced using one or two high – powered loudspeakers. The sound pressure measurements were done in the different points around the acoustic screen using device Investigator 2260 and applying to analyze the modular precise vibration and noise analyzer PULSE 3560 [9]. The obtained results of the theoretical and experimental tests are presented below.

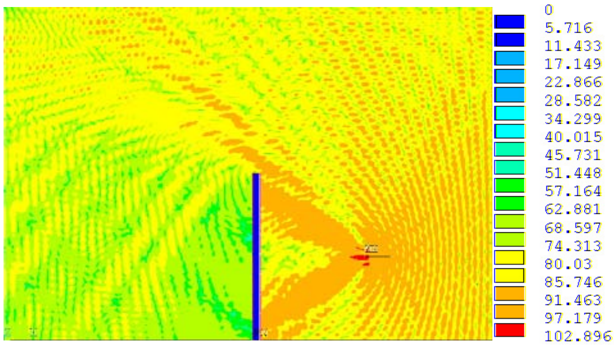

Fig. 8 The sound pressure level in acoustic environment of the laboratory with a screen when the excitation frequency of 2000 Hz is used

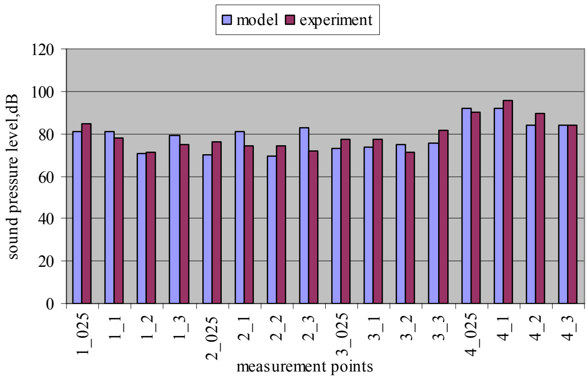

Fig. 9 Values of sound pressure in separate measurement points obtained with the help of theoretical model and experiment when frequency of 1000 Hz was used to excite

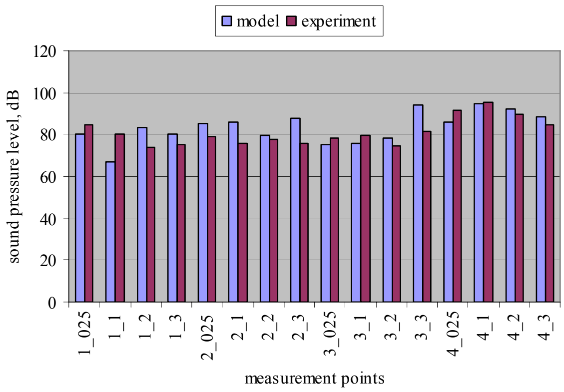

Fig. 10 Values of sound pressure in separate measurement points obtained with the help of theoretical model and experiment when both frequencies (1000 and 2000 Hz) were used to excite at the same time

When the acoustic excitation was imitated the theoretical model helped to determine the distribution of acoustic pressure in the area behind and in front of the partition wall (Fig. 8). The values of the level of acoustic pressure determined with the help of theoretical model in the measurement points correspond well enough the values obtained during the experiment (Figs. 9 and 10). 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 noise level in particular environment.

4. Conclusions

The obtained results of the numerical experiment show that the suggested theoretical model created on the basis of FEM is adequate to the real processes registered in the testing laboratory. The model allows modelling mobile noise suppression systems and evaluating their effectiveness with regard to the frequency and changes of the sources number.

When the passive method of noise suppression is implemented in 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 parameters in the analyzed point of the real object.

5. Acknowledgement

This work was supported by Research and Study Found of Lithuania, project no. T – 87/09.

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AKUSTINIO LAUKO MODELIO ADEKVATUMO TYRIMAS

R e z i u m ė

Šiame darbe naudojantis 2D modeliu, ištirta galimybė modeliuoti keletą žadinimo šaltinių, veikiančių tuo pačiu metu skirtingais harmoniniais dažniais. Gauti teorinio eksperimento rezultatai buvo lyginami su praktinio eksperimento rezultatais. Išnagrinėtas akustinio lauko modelio, sudaryto baigtinių elementų pagrindu, adekvatumas realiam akustiniam laukui. Gauti modeliavimo rezultatai parodė, kad, naudojant teorinį modelį, sukurtą BEM pagrindu, galima modeliuoti akustinį žadinimą, kuris atsiranda realiomis sąlygomis, bei įvertinti triukšmo lygį tam tikroje aplinkoje.

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INVESTIGATION OF ADEQUACY OF THE ACOUSTICAL FIELD MODEL

S u m m a r y

This work used the 2D model to analyze the possibility to model several excitation sources acting at the same time in different harmonic frequencies. The obtained results of the theoretical experiment were compared to the results of practical experiment. The adequacy of the acoustic field's model formed on the basis of the finite elements to the real acoustic field was analyzed. Results showed 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 noise level in particular environment.

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ИССЛЕДОВАНИЕ АДЕКВАТНОСТИ МОДЕЛИ АКУСТИЧЕСКОГО ПОЛЯ

Р е з ю м е

В настоящей работе приведено исследование возможности с помощью двухмерной акустической модели моделировать несколько источников возмущения, действующих одновременно. Исследована адекватность модели акустическому полю. Полученные результаты показали, что с помощью модели можно моделировать акустическое возмущение и оценить уровень шума в конкретной среде.

Received February 23, 2009
Accepted April 06, 2009