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AN INFLUENCE OF WALL STRUCTURE ON ACOUSTIC PRESSURE DISTRIBUTION IN A OPERATOR'S CABIN

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Acoustic conditions in operator's cabin may be formed by using parameters of the cabin wall structure. It might be carried out by changing properties of wall components. This paper presents results of simulation which aim was the assessment of acoustic conditions in a operator's cabin under influence of changes wall structure parameters.

Key words: acoustic comfort, heavy duty machines, the operator's cabin, FEM.

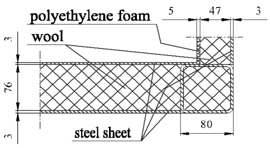
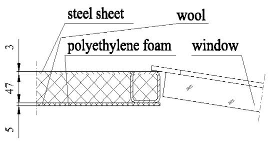
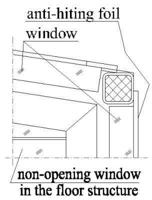
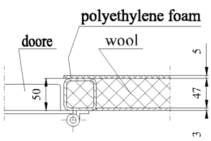
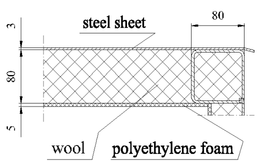
1. Introduction

Shape and dimension the most often use crane cabins are connected with ensuring adequate conditions in aspect of ergonomics and work safety. Fulfilling requirements deal with acoustic comfort involve selection of adequate acoustic insulation of the wall structure in the way that sound intensity level inside the cabin does not exceed permissible value. Standard PN-90/M-45531 [8] determines the permissible equivalent sound pressure level A as $L_{\mathrm{Aeq}} = 70$ dB, what cause that for the typical crane cabins acoustic insulation should be at the level ca. 20 dB (assuming external level of $L_{\mathrm{A}} = 94$ dB [3]), and there is no problem to achieve such level of acoustic insulation. For cabin with radio or telephone communication system required acoustic insulation rising up to ca. 30 dB and achieving this value in case of use typical wall structure is difficult.

2. Crane's cabin acoustic insulation

Typical crane's cabin is a frame structure filled up with multilayer sheathing "sandwich" type and with windows for the sake of ergonomics request, mostly visibility of operating area. For example, modern crane's cabin has a prism shape with a hexagon at the base and overall dimensions as follows: width – 1500 mm, depth – 1800 mm, height 2200 mm. Specification of materials used in such cabin is presented in Table 1.

Table 1. Specification of modern crane's cabin.

	Cabin structure	Shape and dimensions in [mm]	Materials used in cabin structure
Floor		rectangular $(a \times b)$ – 800×1500 trapezoid $(a \times b \times h)$ – $1500 \times 1200 \times 1000$	- steel sheet (external) 3 mm, - polyethylene foam 3 mm, - high acoustic insulation lining 3 mm, - mineral wool plate 2×40 mm, - steel sheet (internal) 3 mm, - double glazed unit 26 mm (kit 6-16-4).
Side wall		rectangular $(a \times b)$ – 800×2200 rectangular $(a \times b)$ – 1000×2200	- steel sheet (external) 3 mm, - polyethylene foam 3 mm, - high acoustic insulation lining 3 mm, - mineral wool plate 2×40 mm, - fibreboard 5 mm, - unilam plate 1.4 mm, - double glazed unit 26 mm (kit 6-16-4).
Front wall		rectangular $(a \times b)$ – 1200×2200	- steel sheet (external) 3 mm, - polyethylene foam 3 mm, - high acoustic insulation lining 3 mm, - mineral wool plate 2×40 mm, - fibreboard 5 mm, - unilam plate 1.4 mm, - window 26 mm (kit 6-16-4).
Rear wall		rectangular $(a \times b)$ – 1300×2200	- steel sheet (external) 3 mm, - polyethylene foam 3 mm, - high acoustic insulation lining 3 mm, - mineral wool plate 2×40 mm, - fibreboard 5 mm, - unilam plate 1.4 mm, - double glazed unit 26 mm (kit 6-16-4).
Ceiling		rectangular $(a \times b)$ – 1500×1800	- steel sheet (external) 3 mm, - polyethylene foam 3 mm, - high acoustic insulation lining 3 mm, - mineral wool plate 2×40 mm, - fibreboard 5 mm, - unilam plate 1.4 mm.

Results of measurement of acoustic insulation for the cabin [4], conducted on the basis of standard PN-EN ISO 11957 are presented in Fig. 1. The acoustic insulation coefficient R_w, calculated according to standard PN-EN ISO 717-1 is 23 dB.

Cabin walls have different structure what follows different acoustic insulation for each wall. Example of measurement results for selected walls are presented in Fig. 2.

Analysis of measurement results in function of frequency shows that in low frequency range acoustic insulation is below 20 dB, but rising for medium and high frequency range.

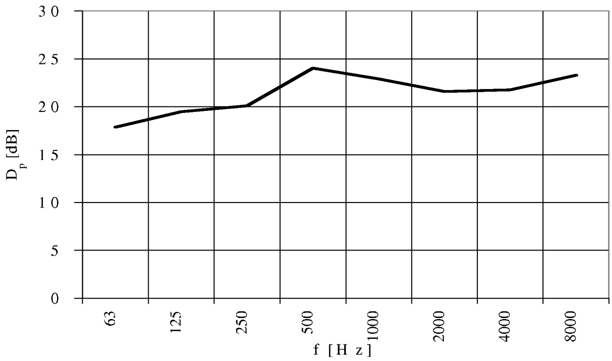


Fig. 1. Acoustic insulation crane's cabin – result of measurements (octave band) [4].

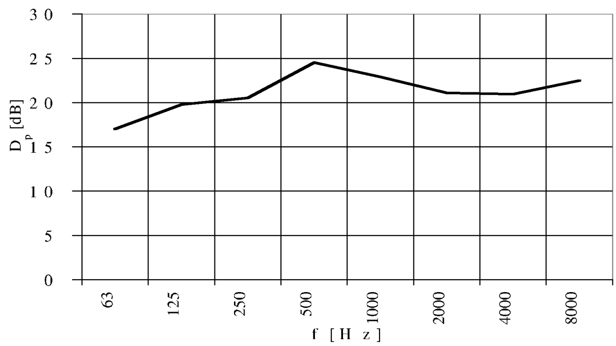


Fig. 2. Acoustic insulation of the front wall – determined from measurements (octave band) [4].

Modification of a cabin acoustic insulation by the assumption of remained geometry is possible by changes of wall structure.

3. An influence of the cabin wall structure on internal acoustic conditions – results of numerical simulation

The object of investigation is the cabin presented in Sec. 2. Acoustic numerical simulation were conducted by the use of finite element method in ANSYS.

The FEM model was simplified, cabin structure was assumed as a plate, multilayer (sandwich type) structure. Walls with windows were assumed as a single layer plate structure. The supporting structure was neglected during analysis. Walls are linked each other along the edges of rectangular prism, which are components of cabin sheathing.

In the model of the cabin was assumed, that displacements of nodes of each plating element for particular wall are the same.

Geometrical model of the cabin is presented in Fig. 3, while FEM model is shown in Fig. 4.

For analysis of solid-shell structure, 8-nodes element SOLID45 was applied. Depending on the thickness of a single wall layer, they were divided on 4 or 6 elements.

Fig. 3. Geometrical model prepared in ANSYS.

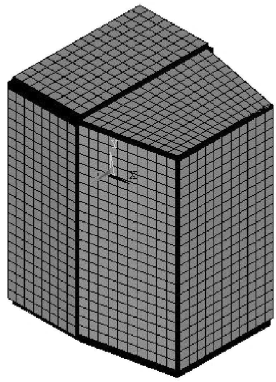


Fig. 4. FEM model.

Boundary conditions and way of cabin fixation were assumed according to the real way of the fastening the cabin to the crane (holders at the cabin roof).

FEM model is presented in Fig. 5. Internal volume which is the acoustic volume to which sounds are radiated consists of 8-nodes elements FLUID30. Linkage between elements SOLID45 and FLUID30 was performed by connection degrees of freedom between common nodes. On the contact faces between solid and fluid volume was set the marker of fluid-solid interaction (fluid-structure interaction flag FSI).

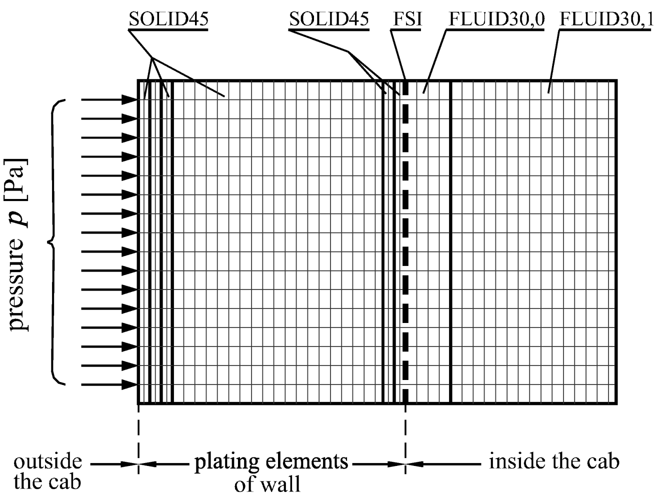


Fig. 5. FEM model in ANSYS.

Sound absorption by the surfaces was realized by change of boundary absorption coefficient β. The usage of this coefficient is the only way to define absorption on surface other than spherical. The sound radiation was simulated in acoustic environment, which was air, and its density was assumed as $1.225\ \mathrm{kg \cdot m^{-3}}$. The velocity of sound wave propagation were set to $343\ \mathrm{m \cdot s^{-1}}$.

Cabin described in this way were analyzed under the influence of acoustic pressure, which were applied as a constant harmonic load, uniformly distributed on all external walls. The load corresponded to acoustic pressure ca. 94 dB (1 Pa) and has the same value for each load frequency. Acoustic pressure inside the cabin was investigated for different thickness of one of the cabin wall component (acoustic insulation lining) in range from 2 mm to 9 mm and for various density of mineral wool in range $\rho = 25 \div 200$ [kg/m^3]. The influence of these changes on acoustic pressure in the cabin was investigated separately. The simulations were carried out for frequency band from 125 Hz to 2000 Hz.

Selected FEM results as a changes of wall acoustic insulation with the changes of parameters wall structure (thickness and density) are presented in Figs. 6, 7 and 8.

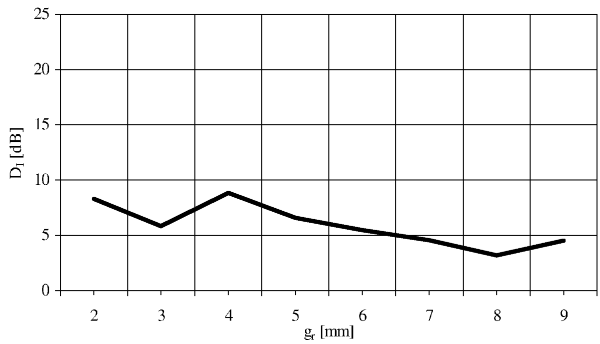


Fig. 6. Acoustic insulation D_I vs. acoustic insulation lining thickness g_r, $f_{\mathrm{okt}} = 250$ [Hz].

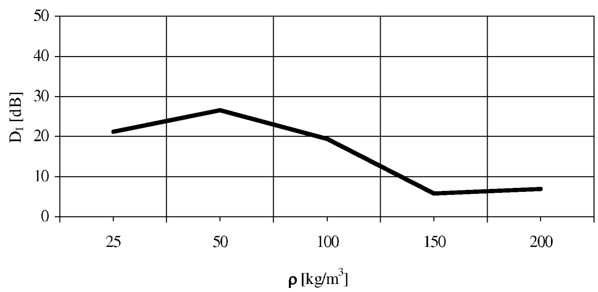


Fig. 7. Acoustic insulation D_I vs. mineral wool density ρ, $f_{\mathrm{okt}} = 250$ [Hz].

FEM analysis shown that, for example, increasing acoustic insulation lining thickness does not cause the increase of wall acoustic insulation (Fig. 6). Similar conclusion may arise after analysis of results presented in Fig. 7 (acoustic insulation in function of mineral wool density). For both cases might be find the optimal (maximal) value for the given frequency range. Similar dependencies were obtained for other frequency load, but the maximal acoustic insulation appears for different acoustic insulation lining thickness.

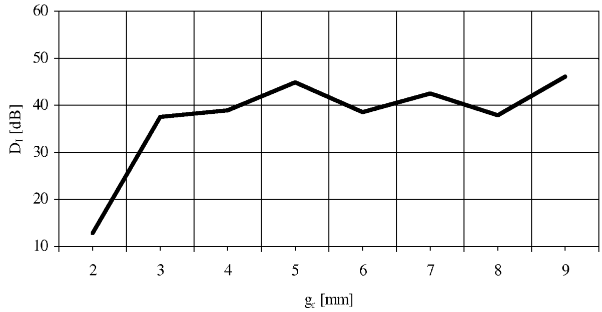


Fig. 8. Acoustic insulation D_I vs. acoustic insulation lining thickness g_r; $f_{\mathrm{okt}} = 1000$ [Hz].

4. Conclusion

For assumed model obtained results of simulations show that the optimal parameters for wall structure components exists.

Comparing results of computer simulations and measurements of acoustic insulation for investigated cabin (Fig. 1) lead to the conclusions that applied thickness of high acoustic insulation lining and wool density are on the lowest range of acoustic insulation for these components.

Therefore, it migth be said that obtaining the adequate acoustic insulation is possible by optimal selection of wall structure components. However, parametrization of mathematical model is necessary as well as carrying out similar analysis for wider range of operator's cabin.

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