The article presents the acoustic models of noise distribution which is caused by the working devices being a part of the laboratory equipment in the Department of Rail Vehicles at the Faculty of Machines and Transportation in Poznan University of Technology. The research was based on the measurements of the sound pressure levels corrected with the frequency characteristics A. The measurements were carried out when the technical objects, located in the educational posts inside the laboratory, had been in operation conditions. Based on the measurements and the assumptions of the method for stationary spatial transformation of sound field, the acoustic maps of the root-mean-square sound level values distribution were elaborated. The aim of this research was to analyze and to evaluate the noise level distribution affecting on the people during the lectures in the laboratory of rail vehicles.

Keywords: acoustic maps, sound level, noise, method for stationary spatial transformation of sound field

1. INTRODUCTION

Institute of the Internal Combustion Engines and Transportation of Poznan University of Technology manages the operation of several laboratories for the students. Labs are equipped with educational posts used to increase the scientific potential of the students and the employees in technical university. One of these is the construction of rail vehicles laboratory, which belongs to the Department of Rail Vehicles. Laboratory is equipped with the educational posts which allow to show the students how the turbochargers and brakes work. Practical exercises on these
posts are associated with an exposure to the noise generated by the different devices. Its impact affects the deterioration in working conditions and the efficiency in performing of duties. The article presents a method for modeling the noise distribution inside the laboratory while the mentioned technical objects are working. On the basis of the main assumptions of the method for stationary spatial transformation of sound field and the measurements of the acoustical signals inside the laboratory, two acoustic maps of the sound level distribution with the frequency characteristics A correction were elaborated. The aim of doing the acoustic maps is to evaluate and to compare the distribution of the sound levels occurring in the laboratory room while technical objects on the selected research posts are working.

2. METHODOLOGY OF RESEARCH

The measurements of sound pressure were made inside the laboratory of the Department of Rail Vehicles, named H19/19. Fig. 1 shows a schematic arrangement of the equipment and the facilities inside the room and the locations of the measurement microphones. The measurements consisted in recording acoustic signals emitted by:

- St.1 – research post No. 1, where the braking process can be observed; in this case the electric motor and a pneumatic braking process related to the air mass flow (Fig. 1) are the main sound sources;
- St.2 – research post No. 2 used for researching an air flow in the turbocharger; the combustion engine powered externally (Fig. 1) and the turbocharger are the main sound sources.

Two measurements of the acoustic signals were made and then the acoustic maps were elaborated. To perform each measurement three microphones (M) positioned in close proximity to the research posts and one appropriate microphone located on the area intended for students (Fig. 1) had been used. Due to the established character of the sound level emitted by the devices it was assumed that every measurement should be performed in time of 1 minute. Then, the root-mean-square sound level value was calculated for four registered signals in each measurement.

Measuring equipment used to make measurements consisted of the following elements:

- four Brüel & Kjær microphones type 4189-L-001,
- fast-signal acquisition unit named PULSE Access type 3050-A-060,
- mobile computer (to control measurements and acquisition of signals).

In the time of measurement the tripods were used where the microphones were set. The measurements were conducted according to the requirements for this type of research [5]. Using the recorded acoustic signals the maps of the lab interior, as in a top plan view, were elaborated.
3. DESCRIPTION OF THE MODELING METHOD

To elaborate the acoustic maps of the sound level distribution inside the laboratory of rail vehicles the main assumptions of stationary Spatial Transformation of Sound Fields – STSF method [1, 4] were used. The STSF method uses a Near-field Acoustic Holography – NAH (Fig. 2) and Helmholtz’ Integral Equation – HIE [1, 4]. NAH is based on the processing the acoustic event recorded at short distance from the sound source and the presentation the results in the form of three-dimensional or two-dimensional holography [1]. In this case the signal analysis is based on a calculation of the main acoustic parameters by the cross spectrum function.
The mathematical interpretation of STSF method is the Helmholtz’ Integral Equation which is shown in form of equation (1). The equation describes the sound pressure waves \( p(r) = p(x, y, z) \) as a function of space from the sound source [1, 4]:

\[
\nabla^2 p(r) + k^2 p(r) = 0
\]

where:
- \( p(r) \) – the complex sound pressure where \( r \) describes the position in space [Pa],
- \( \nabla^2 \) – the Laplace operator,
- \( k \) – the wave number.

![Graphical presentation of NAH assumptions](image)

The process of spatial transformation of a sound pressure \( p(r) = p(x, y, z) \) (holography) is carried out by introducing the equation (2) describing the dependence of the sound pressure measured on the plane \( z_0 \) on the surface \( z \) according to the principle Huygens [2]:

\[
p(x, y, z) = h(x, y, z - z_0) \otimes p(x, y, z_0) \text{ for } z \geq z_0
\]

where:
- \( p(x, y, z) \) – the sound pressure as a function of space [Pa],
- \( h(x, y, z - z_0) \) – the calculated sound pressure – holography [Pa],
- \( p(x, y, z_0) \) – the sound pressure measured on the plane \( z_0 \) [Pa].

Then, the Fourier transform is performed for a pair of the pressures in two dimensions \([x, y]\) for the \( z \) coordinate according to the equations (3) and (4) [2]:

\[
P(K_x, K_y, z) = \int\int p(x, y, z)e^{j(k_x x + k_y y)} dx dy
\]
Acoustic maps of the sound level distribution inside the laboratory of …

\[ p(x, y, z) = \frac{1}{(2\pi)^2} \iint P(K_x, K_y, z) e^{-j(K_x x + K_y y)} dK_x dK_y \]  

(4)

where:

- \( p(x, y, z) \) – the sound pressure as a function of space [Pa],
- \( P(K_x, K_y, z) \) – the sound pressure spectrum in the wave number domain [Pa],
- \( K \) – the wave number in a particular geometric dimension.

Calculated the root-mean-square values of the sound pressure levels for each microphone were used in the NoiseAtWork software. On the basis of the numerical methods which were implemented in the software, the acoustic maps of the sound level distribution were worked out.

4. RESULTS OF RESEARCH

Two acoustic maps of the sound levels distribution inside the Department of Rail Vehicles laboratory were worked out.

Research post No. 1 is consisted of several technical objects (Fig. 3) and the most important of them in terms of the sound emission is an electric motor running at highest revolution speed of 3000 rpm. The braking process is another source of sound. Based on the analysis of the first acoustic map (Fig. 4a), it can be concluded that the microphones No. 1 and 2 captured the highest sound level value, which is over 85 dB while the sound level value captured by the microphone No. 3 is lower and is equal of 84 dB. On these sound level values (Fig. 4) the metal shield partially fencing off the research position No. 3 from microphone No. 3 probably has got an influence. Microphone No. 4 located in the zone intended for the students where the benches are placed, indicates the value of the sound level by 3 dB lower than the microphones No. 1 and 2. Decrease in the noise level is caused by the distance between the microphones which is about 5 m. Furthermore, it should be noted that the laboratory contains the reflective and absorbing elements for the acoustic waves. That is the reason why it was assumed that the overall absorption coefficient of the room is equal of 0.25. For interpretation of the references to color in the figure legends, the reader is referred to the web version of this article, www.fwmt.put.poznan.pl/podgrupa,wydzial_zeszyty_naukowe,1163,oczasopismie.htm.
Fig. 3. Research post No. 1 where the process of braking on vehicle can be carried out

Fig. 4. a) Acoustic map of distribution the sound levels emitted by the technical facilities in operation conditions located on the research post No. 1. The numbers show the location of microphones. b) Range of colors assigned along with the sound pressure levels A

Fig. 5 shows the research post No. 2. The second acoustic map of distribution the sound level is shown in Fig. 6a. In this case the main sound source is the externally driven internal combustion engine. The revolution speed of the engine is at
the rate of 1500 rpm. Ranges of colors assigned along with the sound pressure levels A are the same in both acoustic maps (Fig. 4b and 6b).

Fig. 5. Research post No. 2 where the studies of the internal combustion engine can be carried out as well the studies of the turbochargers with measuring equipment

Fig. 6. a) Acoustic map of distribution the sound levels emitted by the technical facilities in operation conditions located on the research post No. 2. The numbers show the location of the microphones. b) Range of colors assigned along with the sound pressure levels A
Microphones No. 2 and 3 recorded the acoustic signals whose value exceeded 88 dB. The sound level recorded by the microphone No. 1 was about 2 dB lower. The reason for this might be the location of the sound sources on the research post. The sound level value, captured by the microphone No. 4, was less than 85 dB. This is the same decrease in the sound level as for the first acoustic map. However, in this case the distance between microphones No. 1 and 4 is shorter and is equal of 2 m.

5. SUMMARY AND CONCLUSIONS

Based on the analysis of the sound level distribution inside the laboratory it can be concluded that the noise exposure level which is equal of 80 dB [6], was exceeded. Comparing the elaborated acoustic maps it can be found that the root-mean-square sound level value generated by the research post No. 2 is higher by 3 dB than the noise emitted by the research position No. 1, and it is equal of 88 dB in close proximity to the technical facilities being in operating conditions. The sound level was decreasing with an increasing of distance. In the area intended for the students this sound level was equal of 82 dB; for studies performed on the research post No. 1 and of 85 dB for the research post No. 2. An important factor which has an influence on the sound level distribution inside so specific room like the laboratory, is the definition of the absorption coefficient and the reverberation time.

The impact of the such high noise levels might adversely affect the people in the laboratory of the Department of Rail Vehicles during the classes. Especially the lecturers who cyclically carry out the classes with the students inside the laboratory might be exposed on this harmful impact. The working conditions for lecturers can become not comfortable and can lead to the deterioration of concentration, to the irritability or the headaches. It is important to propose solutions of a reduction or an absorption the noise in time of the laboratory classes in the nearest future. Until then the individual ear protection should be used, for example in the form of ear protectors or stoppers.

REFERENCES

Acoustic maps of the sound level distribution inside the laboratory of …


MAPY AKUSTYCZNE ROZKŁADU POZIOMU DŹWIĘKU WEWNĄTRZ LABORATORIUM ZAKŁADU POJAZDÓW SZYNOWYCH

Streszczenie
