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Editor of series: Ljiljana Rašković, e-mail: ral@kalca.junis.ni.ac.yu
Address: Univerzitetski trg 2, 18000 Niš,YU, Tel. +381 18 547-095, Fax: +381 18 547-950
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DIAGNOSTICS OF ACOUSTIC PROCESSES BY INTENSITY MEASUREMENT

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Momir Praščević, Dragan Cvetković

University of Niš, Faculty of Occupational Safety, Depr. of Noise and Vibration
Čarnojevića 10a, 18000 Niš, e-mail: noise@znrfak.znrfak.ni.ac.yu

Abstract. *Starting from the fact that the sound intensity as energy vector describes besides the amount of the sound energy its direction as well, in this paper the review of the acoustic diagnostics field, in which the sound intensity is applicable, will be given as well as the examples whose results confirm the excused choice of this measurement method.*

1. Introduction

The sound as acoustic oscillation appears during disturbance of the particle stationary state of the elastic medium. The changes of particle location is followed by corresponding changes of sound pressure, particle velocity and elastic medium density. Generally that changes are termed acoustic oscillations. The acoustic oscillations appear on the sound source location and spreading in form of the sound wave by wave velocity that depends on medium elasticity. On the sound reception location the acoustic oscillation can make the desired and undesired effects. These effects depend on acoustic oscillation characteristics above all the intensity, duration and frequency content.

The origin of interest to the processes of sound appearing, sound spreading and sound receiving are especially linked to the music and music instruments and coincide to the historical development of the Greece-Roman science. The lows about connection between the pitch and the string length of the laws about sound travel and sound reflection have been known at that time. After stagnation in the Middle Ages, the theoretical development of the acoustic as the science studying the acoustic processes have progressed in the XIX century after the study of Newton, Laibnic etc. "The Sound Theory" by lord Rayleigh is the top of the acoustic theoretical development [1]. The further development has practically been impossible without application of electronics measurement device to the

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acoustic processes diagnostics.

The development in the electronics at the beginning of this century slowly brought measurement technics into step with theory. The valorization of the sound pressure as the basis measurement parameters for the identification and description of acoustic processes has been made possible by development of the measurement transducer and equipment

Although the sound intensity theory has been still defined in "The Sound Theory" from 1877, it has not been used in the acoustic processes diagnostics because of the problems of its technical identification. The conditions for the correct valorization of the sound intensity and its application in the acoustic processes diagnostics have been made by developing the digital components and the modern digital measurement equipment.

In this paper, briefly review of application field of the sound intensity will be given as well as the results obtained in the experimental procedure of verification of the sound intensity method. The sound absorption determination by sound intensity measurement in the regular shape room will be suggested as the new method.

2. Sound Intensity

Physically, the sound intensity is energy vector that describes the amount of the sound energy passing through the observed surface as well as its direction. The sound intensity is the time-averaged product of the sound pressure (p) and particle velocity (v) [2,3]:

$$\vec{I} = \overline{p \cdot \vec{v}} \tag{1}$$

The sound pressure as the scalar quantity does not present any trouble in respect to the technical identification, whereas the particle velocity of the elastic medium in spite of well-known theoretical relations has not been verified by general applicable methods. However, the theoretical working out of the second Newton low and its application to the model of the defined fluid space, in the expression of the Euler equation, the particle velocity has been defined by relating to the pressure gradient:

$$v = -\frac{1}{\rho}\int \frac{\partial p}{\partial r} dt \tag{2}$$

where ρ is the density of the elastic medium.

The fact that the pressure gradient is the continuous function enables the procedure of the finite difference approximation that includes two closely spaced phase-matched microphones (Fig. 1).

In this way, the pressure gradient can be approximated by the straight line. The slope of this line is determined by quatiend of the final difference of the microphone pressures and the microphone space. The sound intensity is obtained by multiplying and averaging approximated quantity of the sound pressure and the particle velocity [2,3]:

$$I = -\overline{\frac{p_A + p_B}{2\rho\Delta r}\int (p_B - p_A)dt} \tag{3}$$

where p_A is the sound pressure of microphone A and p_B the sound pressure of microphone B.

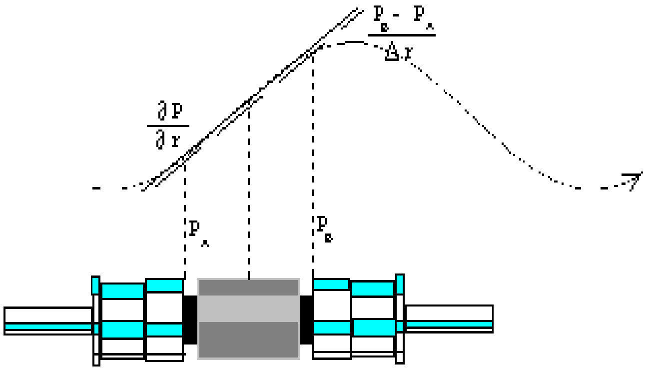

Fig. 1. The finite difference approximation

In this way the organized methodical procedure enables that the acoustic processes are treated in a way which closely defines the structure of the dynamic processes in the sound generation, sound propagation and sound reception. So that the sound intensity is applicable in the following field:

-the valorization of the source acoustic activity
-the identification of the dominant sound source
-the partition sound insulation
-the sound absorption
-the radiation efficiency
-the structural intensity.

3. Valorization of sound acoustic activity

The statement that the sound pressure level on the work place in the scope of the industrial environment or the living environment going out from the scope of the value of the upper limit is really identification with the consequence whose the causes are not defined even approximately. Principally the complex machine structure as the generator of the acoustic processes radiates acoustic energy. This energy radiated in unit time defines the sound power of sound source.

The traditional method of sound power determination is to place the sound source in a known acoustic environment and the measurement of sound pressure. The sound power can be calculated on the basis of the relation between the sound power and sound pressure in the corresponding acoustical environment. However, as the sound intensity is energy flux per area unit in order to sound power determination it is enough to determine the averaged normal sound intensity over a surface enclosing the sound source. The measurement surface is divided on n segments of same area ΔS and the normal sound intensity In is measured into center of all segments. The sound power is obtained by multiplying the averaged intensity by the surface area:

$$W = \sum_{i=1}^{n} I_n \Delta S \tag{4}$$

The results obtained by the comparative analysis of sound power determination of reference sound source by sound pressure method (ISO 3744 and ISO 3745) and by sound intensity method (ISO 9614-1) confirm the accuracy and precision as well as decision of sound intensity method [4]. It should be noted that the sound sources and reflecting surfaces outside the closed measurement surface do not influence to the measurement accuracy. The obtained results are shown on Fig. 2 [4].

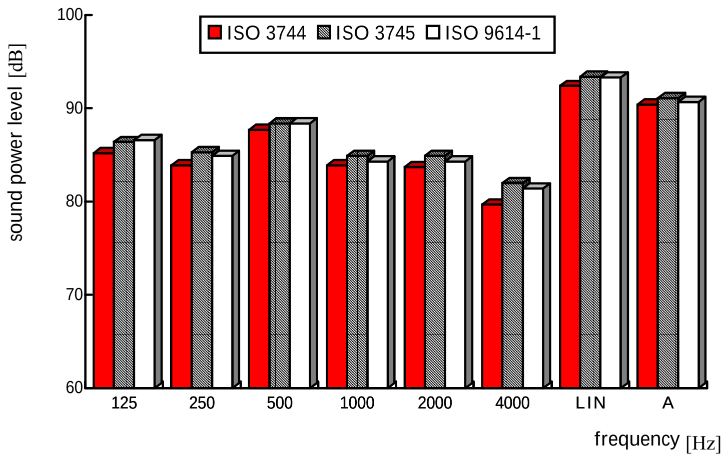

Fig. 2. The sound power of reference sound source

4. Identification of Dominant Sound Source

Sound intensity measurements offers several ways of location and identification of parts of the devices and machines radiating the most acoustic energy. In that way, it is possible reconstruct only parts of the system emitting the most noise.

The null search method uses the probe's directional characteristics. Therefore, there is a change in direction for only a small change in sound incident angle. The position of measurement probe where the sound intensity direction alternates rapidly between positive- and negative-going intensity defines point where the sound source must be incident on the probe at 90° to its axis. In that way the sound source can be located by sweeping the probe so that its axis makes a line parallel to the plane on which we think the source is located.

Contour and 3-D plots give a more detailed picture of the sound field generated by a source. The structure parts radiating most acoustic energy can then be identified with accuracy. Based upon sound intensity measurement directly above the plane on which we think the source is located the level matrix is created. Lines of equal intensity can be drawn by interpolating and joining up point of equal intensity. These are sometimes called iso-intensity lines and they can be drawn either at single frequencies or for overall level. The same data can be used to generate 3-D plots which provide easy visualization of the sound field generated by a source.

An example of dominant sound source location of the vacuum cleaner is given as illustration of sound intensity method. The sound power of vacuum cleaner determined by sound intensity method is 77.5 dB(A), Re=1 pW [5,6]. The contour and 3-D plots of sound intensity distribution on the top side of vacuum cleaner are given on Fig. 3 [5]. These plots obviously point to the fact the dominant noise source is intake unit placed on the top side of this model of vaccine cleaner.

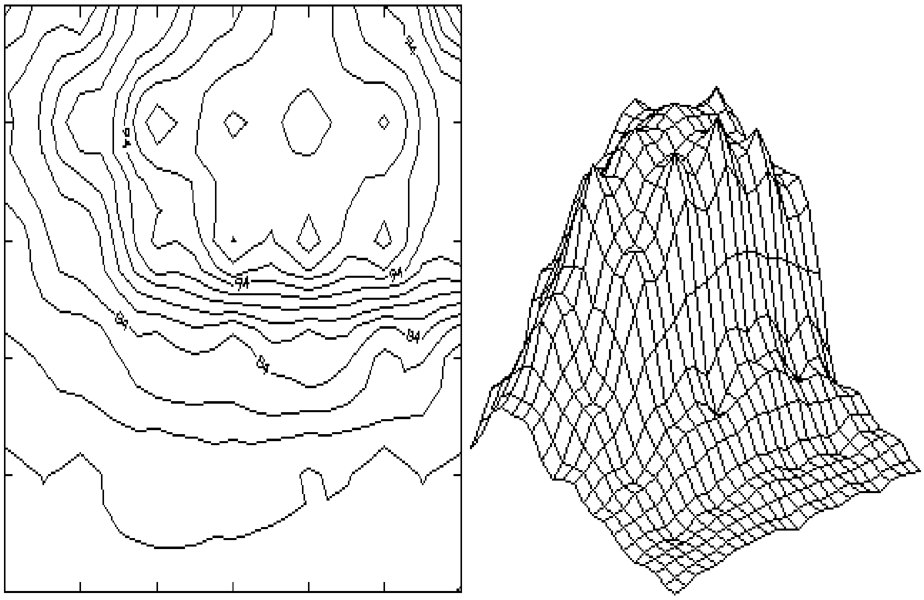

Fig. 3. Contour and 3-D plots of sound intensity distribution

5. Sound insulation

The essence of the partition sound insulation is defined by the level difference between the sound energy incident onto the partition and the sound energy transmitted into the receiving room. By applying the theory at the hypothetical model with the homogenous and diffuse sound filed in the source and receiving rooms, the partition sound insulation can be expressed as the sound pressure level difference of the rooms from the hypothetical model corrected by the absorbed energy in the receiving room:

$$R = L_1 - L_2 + 10\log\frac{S}{A_2} \tag{5}$$

where is: L_1 - sound pressure level into source room
L_2 - sound pressure level into receiving room
A_2 - absorption of receiving room
S - area of partition.

The development methodical procedure are the synthesis of the theoretical knowledge about the sound insulation and the experience acquired in the measurement procedure. However, the influential factors of the real structure, above all the flanking transmission, other transmission paths as well as inhomogeneousness of the created structure and the partition oscillation are reason why the real idea about the partition sound insulation can not be obtained.

As the oscillating activity of the partition can be closely defined by sound intensity, the methodical procedure of sound insulation determination by intensity measurement enables the elimination of influence of the flanking transmission to the overall partition insulation. In the analysis of the sound filed configuration at the source room, the same analytic classical method have retained while the sound energy emitted by the partition in the receiving room is determined by intensity measurements. In that way, the partition sound insulation as function of the sound intensity is obtained [7]:

$$R = (L_p - 6) - L_I \tag{6}$$

where is: L_p - sound pressure level into source room
L_I - sound intensity level into receiving room.

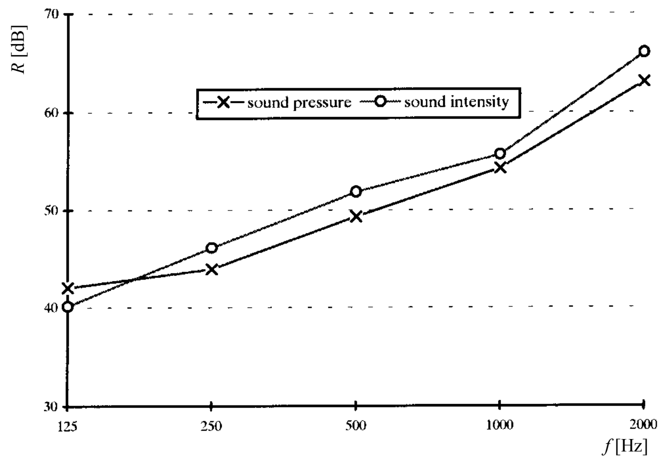

Fig. 4. Transmission loss of partition

The verification of the sound intensity method has been carried out by an experiment at the real partition wall of the reinforced concrete thick 15 cm with outstanding flanking transmission. The obtained results are compared with the results obtained by classical method. The segments of the results are shown on Fig. 4 and they show that the contribution of flanking transmission in expressing of the sound insulation is very important. The results show that the flanking transmission with its negative influence reduces the insulation index approximately by the order of magnitude of 3 dB.

6. SOUND ABSORPTION

In order to obtain the desired characteristics of the sound field at the acoustical treatment of the rooms it is very important to have accurate values of the necessary parameters. The frequency characteristics of absorption coefficient of the materials are used as the primary data. The values of this coefficient determined by standardized method of reverberation time measurement in the reverberation room can be rather different in dependence of the characteristics of measurement rooms. Also, the obtained values in the certain frequency bands often exceed the theoretical maximum value of the absorption coefficient.

The sound intensity supply the alternative approach of the absorption coefficient determination in regular shape rooms which do not satisfy the necessary condition for the application of the standardized method. The absorbed sound energy has been determined based upon the sound intensity measurement by the measurement probe directly above the absorption material whereas the incident sound energy has been determined based upon the sound pressure level in the central part of room. The absorption coefficient in function of sound intensity can be expressed [8-11]:

$$\alpha = \frac{I \cdot 4\rho c}{p^2} \tag{7}$$

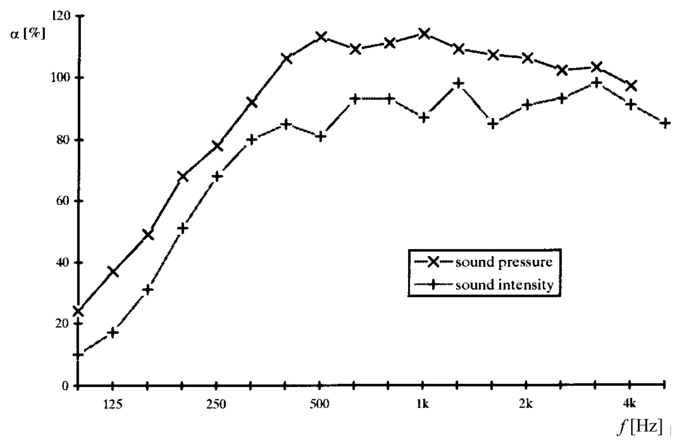

Fig. 5. The absorption coefficient of rock wool

Based upon the above equation the measurement procedure of absorption coefficient determination in regular shape room has been developed. In order to confirmation of this method, the research on three different measurement specimen and in three rooms of different acoustic characteristics has been carried out. The experimental results for the rock wool of 50 kg/m^3 density obtained by sound intensity method, together with the data about the absorption coefficient obtained by standardized method are shown on Fig. 5. [8-11].

The shown frequency characteristics of the absorption coefficient of the examination specimen have the similar shape but there are the certain differences at a few frequency bands, However, it should be noted that the values obtained by standardized method exceed the theoretical maximum value of 100% while the values obtained by intensity method do not exceed. After normalization of these values in respect to the maximum value the noticed differences are reduced. By analysis of the absorption coefficient values obtained in the different acoustic environment it can be noted the relatively good repeat of the results obtained by new procedure.

The other advantage this method is that the weighted absorption coefficient can be calculated. The frequency characteristics can be simply converted into single number by calculating total intensity level and pressure level as the logarithmic sum of the corresponding measured band limited quantities. Based upon this data the absorption coefficient of different materials can be reciprocally compared.

7. Conclusion

As the new methodical procedure of acoustic processes diagnostics, the sound intensity measurement offers much bigger flexibility in choice of measurement environment as well as size of measurement object in contrast to the sound pressure measurements which take the measurement rooms with well-defined acoustic characteristics.

The results obtained in the valorization of sound intensity method in the acoustic processes diagnostics point to accuracy and precision as well as decision of this method.

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DIJAGNOSTIKA AKUSTIČKIH PROCESA MERENJEM INTENZITETA

Momir Praščević, Dragan Cvetković

Polazeći od činjenice da intenzitet zvuka kao energetski vektor opisuje pored količine i pravac zvučne energije, u ovom radu je dat pregled primena intenziteta zvuka u akustičkoj dijagnostiki. Takođe, u radu su dati i primeri čiji rezultati opravdavaju izbor ove merne metode.