ICSV13 - Vienna
The Thirteenth International Congress
on Sound and Vibration
Vienna, Austria, July 2-6, 2006

THE APPLICATION OF THE INVERSE METHOD IN INDUSTRIAL CONDITIONS

Lesław Stryczniewicz[1], Zbigniew Engel[2],

[1]AGH, University of Science and Technology, Al. Mickiewicza 30, 30-059 Kraków, Poland
strycz ni@agh.edu.pl
[2]Central Institute for Labour - National Research Institute, ul. Czerniakowska 16, 00-701
Warszawa, Poland

Abstract

In the article the way of determining sound sources' parameters with the use of inverse method in the industrial room was presented. Using a computer program for determining sound level distribution in rooms, the function value of conversion between acoustic power and acoustic level pressure in compressor room was determined. On the basis of acoustic field parameters' measurements and determined conversion functions were estimated the levels of acoustic power of particular sound sources in real room. These results were compared to those determined in a traditional way.

INTRODUCTION

A wide development of the inversion methods combined with other computer methods, such as the Finite Element Method, Boundary Element Method and the Geometric Element Method of the determination of acoustic signals propagation inside the rooms, allow for more effective ways of the localisation of a complex sound source. Reconstruction of sound sources by means of the Boundary Element Method (BEM) and inversion methods constitute the strong tool for the identification of sound sources of various shapes.

As the experimental place for the estimation of sound source parameters the compressor room was chosen since such rooms are very common in industrial settings. Four compressor units WSBW-8/220 of an identical wear-out degree were placed in the room. The compressor room had perpendicular walls covered by smooth plaster and a concrete floor of the dimensions: 14.9 x 7.8 x 6.6 m. Windows were placed in the upper part of walls. Measurements of the acoustic pressure distribution were made in the tertiary frequency bands in the frequency range 50 Hz - 10 kHz. Investigations were performed by means of the portable, single channel, analyser NORSONIC110.

Acoustic pressure level measurements were performed for three variants of the compressor operation:

- Variant I – Compressor No 3 operates – inside the completely closed sound absorbing and insulating enclosure,
- Variant II – Compressor No 2 operates – without any enclosure,
- Variant III – Both compressors, No 2 and 3, are operating.

Measurements of the sound level distribution - on the area of the room - were made in the measuring grid 1m x 1m (Fig.5) (altogether in 98 measuring points). The results obtained from all measuring points are graphically presented in the maps of A-sound level distribution (Figures 1 – 3).

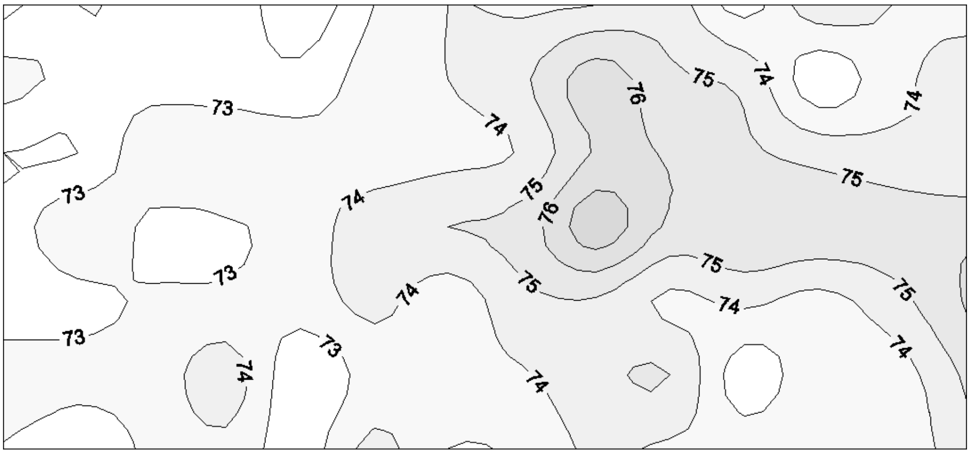

Figure 1 – Sound level distribution in the compressor room –Variant I

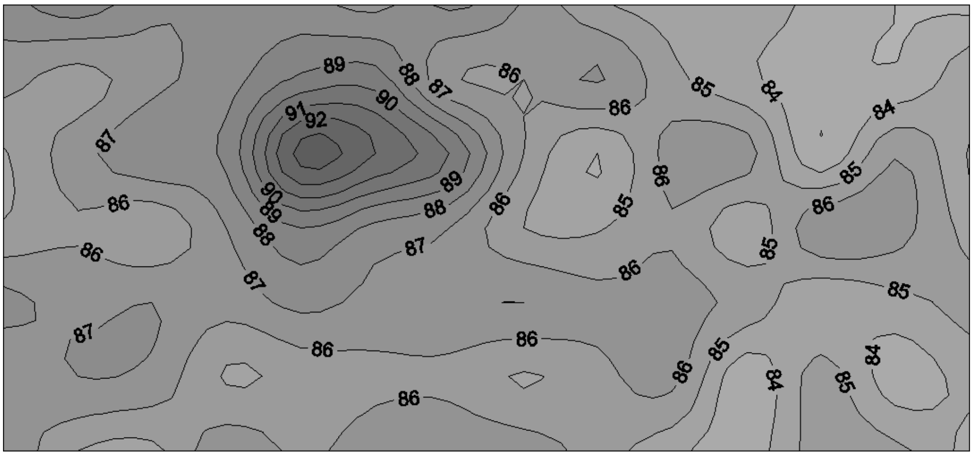

Figure 2 – Sound level distribution in the compressor room – Variant II

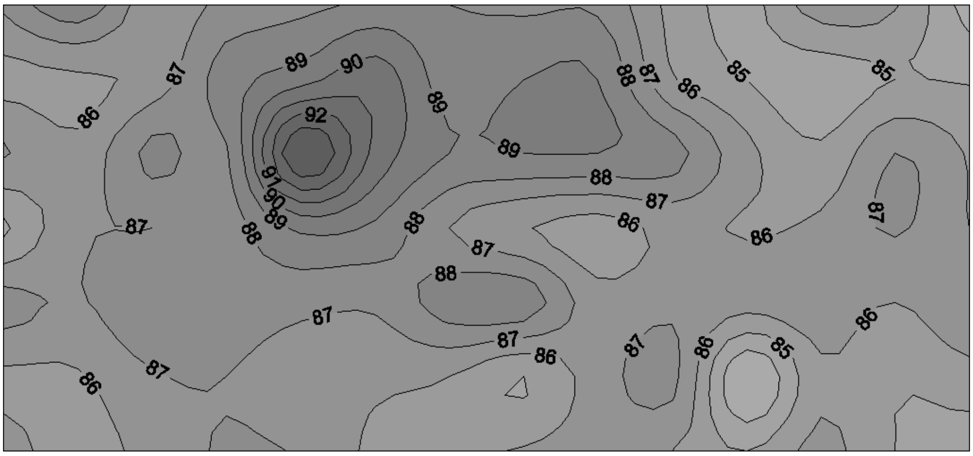

Figure 3 – Sound level distribution in the compressor room – Variant III

GEOMETRICAL MODELLING OF THE ACOUSTIC FIELD INSIDE THE ROOM

Investigation of the acoustic field with the application of modelling is widely used nowadays. The main advantage of this approach is the possibility of modelling the newly designed rooms as well as the selection of the materials to be applied, positions and directivities, which means the modification of existing places. Out of various types of models, wave and geometric models cannot be analysed without the computer application. The use of these models depends on the type of the analysed room. In the case of small-wave rooms we apply the wave models, where the analysis is based on the Finite Element Method and the Boundary Element Method. The proper description of the acoustic field should also take into account the phase dependencies.

On the other hand, in the case of large-wave rooms the wave phenomena are difficult to observe and can be neglected. Thus, the geometric models are used for the acoustic analysis of such places (e.g. concert halls or opera houses). There are several methods of geometrical modelling. The main ones are: the ray method and the apparent source method. The calculating algorithm utilized by the Raynoise packet is based on the combination of those both methods. This professional tool assists in predicting the acoustic characteristics of such objects as concert halls, opera houses, industrial workshops or recording studios.

The inversion method is based on the substitution of the actual sound source by a system of substitute sources. The next step is the selection of the parameters of those sources in such a way, that the distribution of acoustic field generated by the system of substitute sources will be as much as possible similar to the acoustic field distribution around the actual source.

When we limit ourselves to stationary monoharmonic processes only the acoustic pressure in the observation points can be determined from the dependency (1) [3]:

$$\mathbf{p}^2 = \mathbf{GN} + \mathbf{e} \qquad [\mathrm{Pa}] \qquad (1)$$

where:

$\mathbf{p}^2$ - m-dimensional vector of the measured values of acoustic pressure squares at the observation points [Pa^2], **m** – number of observation points;

N - n-dimensional vector of the acoustic power of sound sources [W], **n -** number - of acoustic power value of the acoustic substitute sources - being looked for;

G - Matrix $\mathrm{m}\, x\, \mathrm{n}$ determining the influence of the effect function value of the source I on the value of the acoustic pressure square in the observation point j,

e - m-dimensional unknown error vector [Pa^2].

Usually the best source parameters can be determined by means of the method of least squares of errors from the formula (2).

$$N = \mathbf{G}^{+}\mathbf{p} \qquad (2)$$

where: **N** - n-dimensional vector of the estimated values of the model source acoustic power value.

$\mathbf{G}^{+} = \mathbf{V}\boldsymbol{\Sigma}^{+}\mathbf{U}^{H}$ - Matrix of pseudoinversion, which can be estimated using the matrix distribution **G** versus the particular values.

Estimation of the conversion function between the sound source parameters and the acoustic field parameters at certain points requires the information concerning the conversion function in the room. Determination of such function is a very complex problem. We can apply geometrical modelling of the room for the estimation of this function value at the certain observation points.

As the result of the performed computer simulations we obtain the echogram i.e. the system of spectral lines corresponding to the rays reaching the observation point.

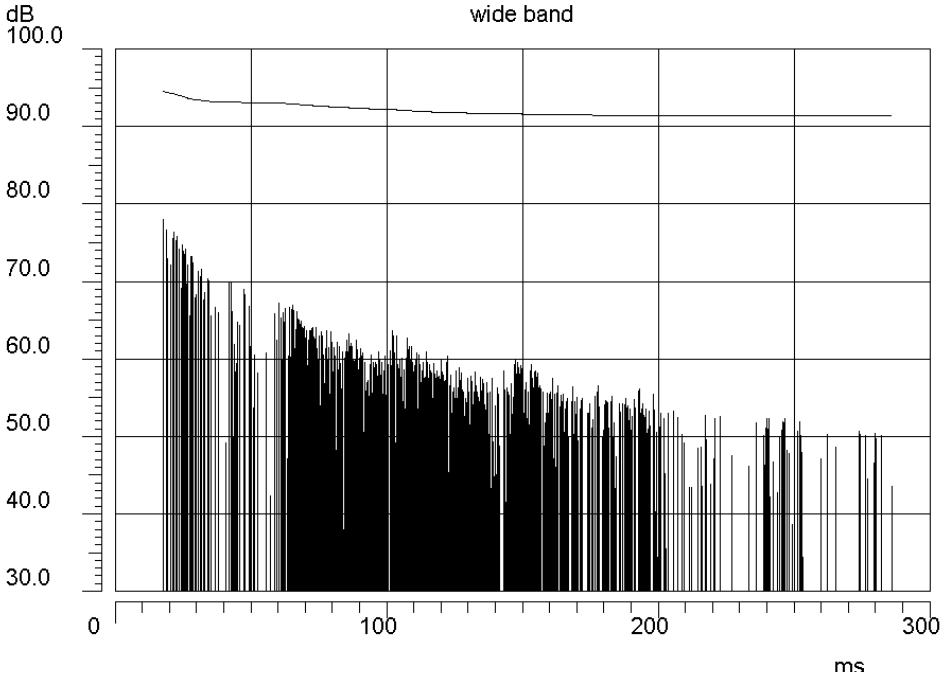

Figure 4 -Exemplary echogram

The acoustic signal obtained at the observation point consists of the current wave and several reflective waves. If we limit our discussion to harmonic runs only, we can express the acoustic pressure at the observation point as:

$$p = \sum_{1}^{n} A_i \cos\left(\omega\, t + \varphi_i\right) \tag{1}$$

where: A_i – Amplitude of i^{th} conversion,

$\varphi_i = \omega\, t_i$,,

t_i – Time delay of i^{th} conversion.

Equation 1 can be presented in the form:

$$p = C \cos\left(\omega\, t + \alpha\right) \tag{2}$$

where:

$$C = \sqrt{\left(\sum_{1}^{n} A_i \sin\left(\varphi_i\right)\right)^2 + \left(\sum_{1}^{n} A_i \cos\left(\varphi_i\right)\right)^2} \tag{3}$$

$$\alpha = \arctan\left(- \frac{\sum_{i}^{n} A_i \sin((\varphi_i)}{\sum_{1}^{n} A_i \cos\left(\varphi_i\right)} \right)$$

Both, amplitudes and phase shifting of signals can be obtained on the basis of echograms. However, additional phase shifting, which occurs during a reflection from the surface, constitute a serious problem. While the producers of building materials often provide sound absorption coefficients of those materials, investigations concerning changes of the phase shift angles at reflections are still very scarce.

RESULTS OF COMPUTER SIMULATIONS

Using the computer program the compressor room was modelled. The placement of compressors and observation points are shown in Fig. 5. Parameters of reflecting surfaces were taken from the catalogue data. The assumed radiation coefficients were calibrated on the basis of the experimentally determined reverberation times. However, less accurate method of the parameter determination, in which phase dependencies are omitted, had to be applied in the calculations due to the lack of any data concerning phase shift angles.

Each compressor was modelled by a system of 5 omnidirectional sources placed in the middle of each wall (apart from the floor). Substitute sound sources on the compressor No 2 were marked in calculations by symbols: S1_1, S1_2,...S1_5. Substitute sound sources on the compressor No 3 (in the enclosure) were marked: S2_1, S2_2,...S2_5. The effect function distribution level for the selected substitute sources are presented in Fig 6 – 8.

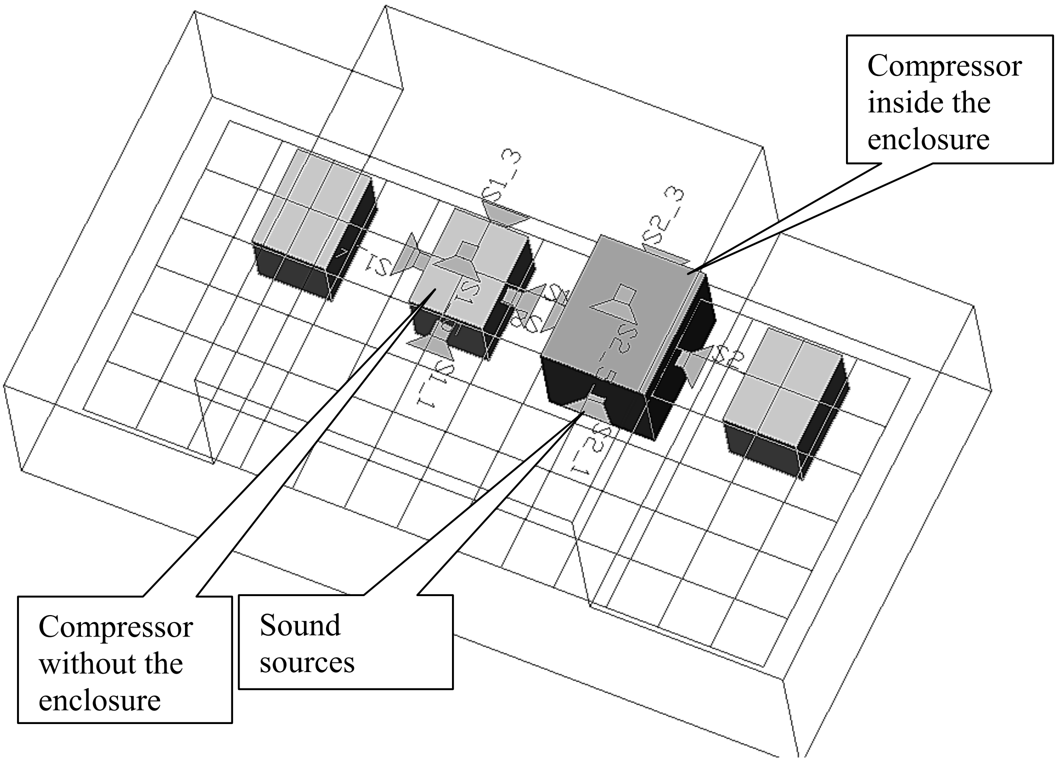

Figure 5 –Distribution of sound sources and recepting surfaces

Acoustic parameters of sound sources (acoustic powers) were determined by the inversion method with the utilisation of the effect function values determined by the computer software and the results of acoustic measurements. Simulations were performed for three variants of compressor operations and the levels of the acoustic power of substitute sources were determined for all three cases. The calculated results are presented in Table 1.

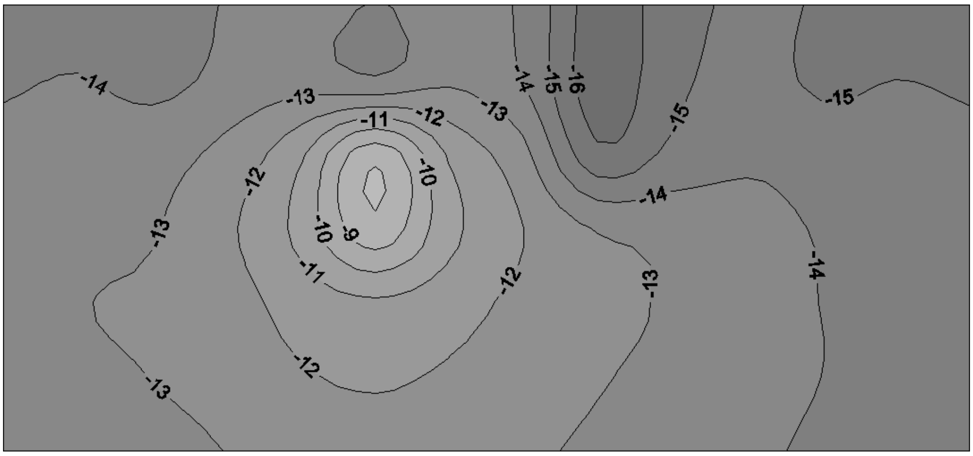

Figure 6 – Effect function distribution for S1_1sound source

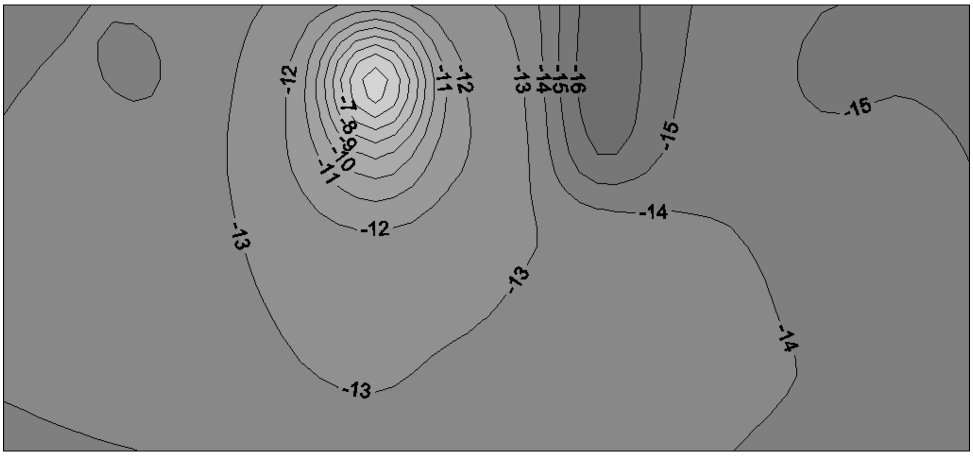

Figure 7- Effect function distribution for S1_5 sound source

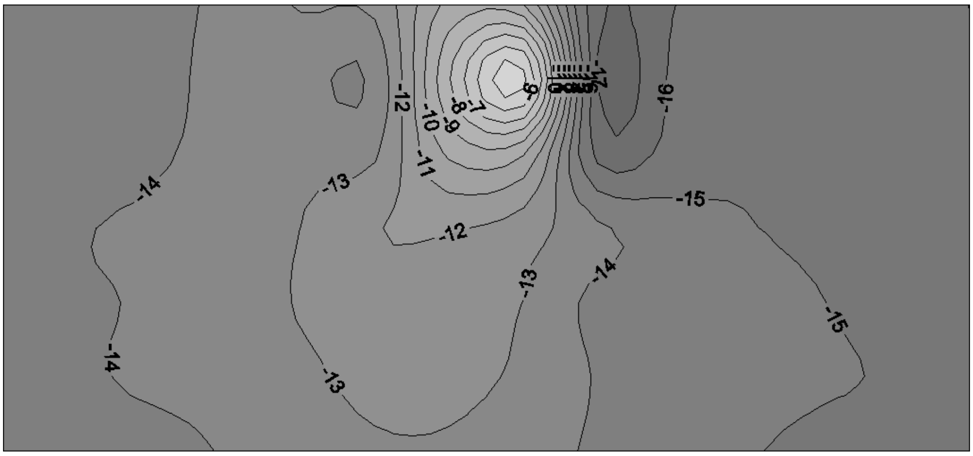

Figure 8 – Effect function distribution for S2_4 sound source

Table 1. Acoustic power levels of the substitute sound sources

	Variant I	Variant II	Variant III
Compressor No 2	-	97.3	96.4
	-	79.7	78.3
	-	86.6	87.6
	-	93.0	93.0
	-	92.8	93.4
Compressor No 3	83.9	-	94.1
	80.1	-	85.1
	82.2	-	81.8
	74.5	-	90.4
	75.2	-	95.7

Attention should be directed to large discrepancies between the calculation results of the sound sources of the compressor inside the enclosure in variants I and

III. This is caused by the fact, that the sound power levels of both compressors significantly varied since the sound absorbing and insulation enclosure was effective. The noise generated by the compressor inside the enclosure was much smaller than the one generated by the compressor without the enclosure (not favourable ratio of the signal power to the background noise).

The performed computer simulations confirm the high compatibility of the actual acoustic measurements with the results obtained during the reconstruction of sound sources by means of the acoustic inversion method.

CONCLUSIONS

The method of determination of the sound sources parameters in the industrial settings by means of the inversion method was presented in the paper. Information of the actual distribution of acoustic pressure around industrial sound sources is necessary e.g. for the calculation of simplified emission models parameters. The value of the conversion function between the acoustic power of sound sources and the acoustic pressure level inside the room was determined by means of the Raynoise program. On the basis of the performed measurements of the acoustic field parameters and the previously estimated conversion functions the acoustic power level of individual compressors in real (with reverberation) rooms were determined. After estimating the acoustic parameters of the model the distribution of sound levels in the compressor room were determined (with the application of computer simulations and calculations). Distribution of the sound level obtained in the calculations well represented the actual distribution levels determined by traditional measurements.

The research was conducted within the research programs financed by the Ministry of Science and Education in Poland.

REFERENCES

[1].Engel Z., Stryczniewicz L., Piechowicz J. , *Application of the inversion method for the determination of partial acoustic powers of machines* , Konf. OSA 2003, Gliwice, 2003

[2].Engel Z., Stryczniewicz L.: *Problem of source modelling*; Archives of Acoustics; 1995, 20, 1, 27-37.

[3].Nelson P. A. A *Review of Some Inverse Problems in Acoustics*, International Journal of Acoustics and Vibrations, Vol. 6, No 3, 200, 118-134.

[4].Multi-author work, edit. Engel Z., *Inwersja w programowaniu hałasów emitowanych przez maszyny i urządzenia*, Prace AGH, 2002-2003.

[5].Stryczniewicz L. , *Identification of zones of increased vibroacoustic emission by means of the inverse method* , Archives of Acoustics, Vol. 29, No 4, 563-576, Warszawa, 2004