

Research Paper

Use of Acoustic Camera for Noise Sources Localization and Noise Reduction in the Industrial Plant

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The paper presents results of the localization of main noise sources in the industrial plant. Identification of main noise sources was made with an acoustic camera using Beamforming Method. Parallel to the measurements by means of the acoustic camera, sound level measurements on the main noise sources have been performed. Based on the calculations, prediction regarding the noise emission at residential buildings located near to the plant has been determined. Acoustic noise maps have been performed with LEQ Professional software, which includes the 3D geometry of the buildings inside the plant. It has been established that, after introduction of noise reduction measures in the plant, the noise levels at the observation points in the residential area meets the limit values.

Keywords: noise source localization; noise reduction; industrial noise control; acoustic camera.

1. Introduction

Industrial noise in the neighborhood of residential buildings should be within the limits described in the regulations. If the noise level emitted from the plant is higher than the limit one, the location of the main noise sources and applying of measures for noise reduction are needed (LE BOUQUIN, FAUCON, 1992; SANTOS *et al.*, 2008).

Industrial noise which occurs especially in the vicinity of residential buildings should be within the limits described in the Regulation of Polish Ministry of the Environment (Ministry of the Environment, 2012). If noise levels exceed the limit values for industrial installations a key issue is the location of the main noise sources and application of measures designed to reduce noise emissions. This applies to both internal and external noise of industrial rooms.

In this work the location of the main external noise sources in the production plant has been carried out using an acoustic camera. Based on results, measures for noise reduction has been proposed.

2. Methodology for noise reduction in the plant

The methodology for the noise reduction in industrial plant concerning the environmental noise has been shown in Fig. 1.

The identification of noise sources inside the plant is a key issue regarding the noise reduction and can be done with modern tool like acoustic camera. The acoustic photos or videos from acoustic camera show at the observation points which noise sources are dominant regarding the noise emission. It is well known that the noise sources with highest levels decide about the global noise radiation in the define direction. Several noise sources inside the plant are also screened with the buildings on the path between the noise sources and the observation points.

After the noise measurements on main noise sources the simulation of noise emission inside and around the plant can be performed. Nowadays there are programs which include 3D geometry of buildings and other equipment inside the plant and allow the development of acoustic maps in which the noise levels at the ob-

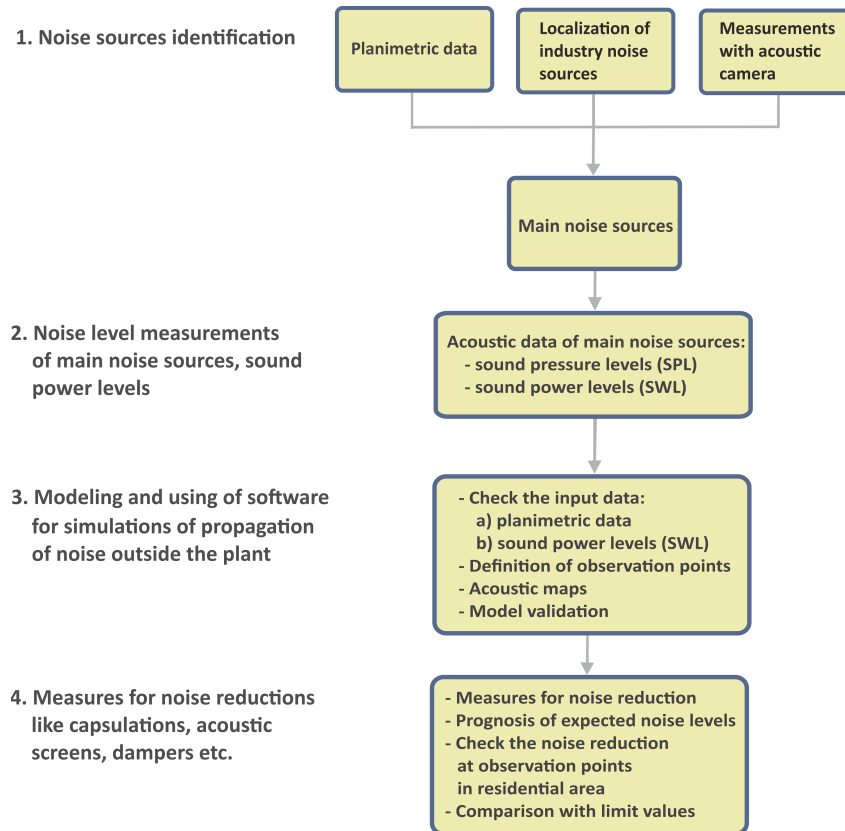


Fig. 1. Methodology for noise reduction in the industrial plant.

ervation points can be established. It is also possible to make a prediction of the noise reduction assuming a define measures for noise reduction (SANTOS *et al.*, 2008; FIEBIG, DĄBROWSKI, 2014). After introduction the measures for noise reduction the validation of simulation results can be done.

3. Acoustic camera for noise sources location

For the location of noise sources an acoustic camera Bionic M-112 (CAE-Noise Inspector) has been used. The acoustic camera (Fig. 2) is consisting from mi-

crophone array with the optic camera inside and has a high resolution, especially in the field of medium and higher frequencies. The signals from microphones will be transferred to the Data Acquisition System and to PC in which different software and procedures for noise sources localization are implemented.

The acoustic camera allows to convert the sound levels to the optical image (KIM, CHOI, 2013; BAI *et al.*, 2013). Due to the visualization of sound levels in term of optical picture or video, the fast location of noise sources is possible. Using the acoustic camera not only the sources can be located but also the sound levels generated by them.

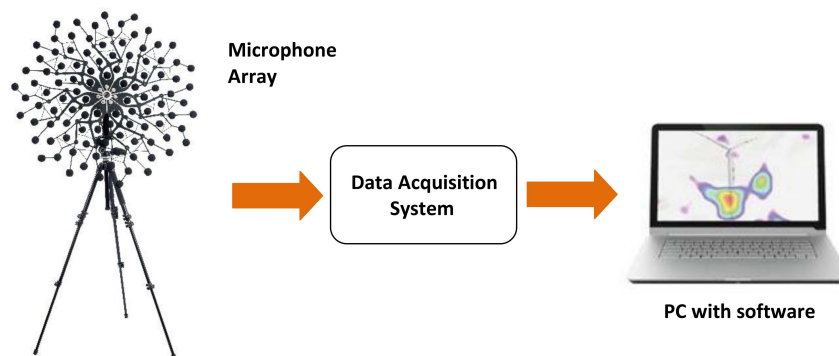


Fig. 2. CAE Acoustic camera Bionic M-112 with array of 112 microphones.

The principle of Beamforming Method (BRADSTEIN, WARD, 2001; MCCOWAN, 2001; CHRISTENSEN, HALD, 2004; KANEDA, OHGA, 1986) is based on the description of Delay-and-Sum beamformer. As shown in Fig. 3, the measurement occurs in the plane and signals will be examined from M microphones located in sites r_m ($m = 1, 2, \dots, M$) in the $x - y$ plane of the coordinate system. When the plane will be applied for Delay-and-Sum beamforming, signals measuring the sound pressure p_m shall be individually delayed and then added together:

$$b(\kappa, t) = \sum_{m=1}^M w_m p_m(t - \Delta_m(\kappa)), \quad (1)$$

where the coefficients b are a collection of w_m weights applied to the individual acoustic pressure signals p_m from individual microphones. Individual time delays Δ_m were obtained in order to achieve the higher sensitivity in a particular direction.

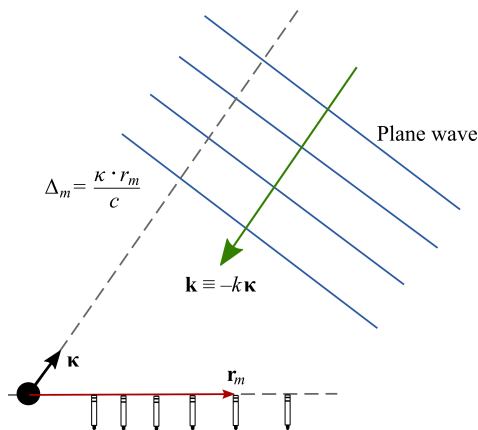


Fig. 3. The array of microphones, focused on the far field and flat wave coming from the focused direction.

4. Application example

The described methodology has been proved in many applications. Experiences show that the most important is the proper evaluation of noise coming from different noise sources in the plant. Basically there are three types of external noise sources in industrial plants:

- point sources – small sources like fans, which are located far away from the receiver,
- line sources – like piping systems, ventilation ducts,
- area sources – like opening in buildings and large machines.

4.1. Noise sources localization

Based on measurements with acoustic camera three main sources in the plant, shown in Figs 4 to 9 have been identified.

4.2. Evaluation of the noise emission of the main noise sources

Additional to the measurements with the acoustic camera the equivalent sound level $L_{Aeq,T}$ of the main noise sources has been established.

The sound level meter type 945A SVAN class 1 has been used. Sound level meter meets the standards EN-60651 and 60804. Before the measurement, the sound level meter has been calibrated.

The measurement of the sound level meter with the following settings was performed: A – weighting on, time constant Fast, measuring range 30–130 dB, type of the data stored into the buffer device – RMS.

Based on the evaluated sound levels L_{Aeq} the sound power levels L_{WA} according to the standard PN-EN ISO 3744-2011 have been established.

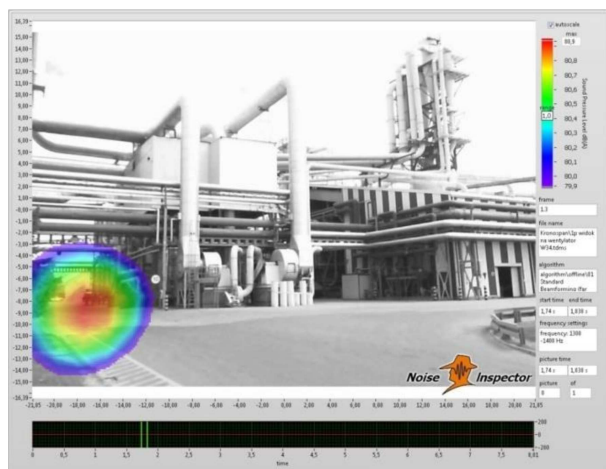


Fig. 4. Source Z1 (industrial fan) – flow $Q = 28\,500\text{ m}^3/\text{h}$, diameter 0.7 m, frequency range 800–920 Hz.

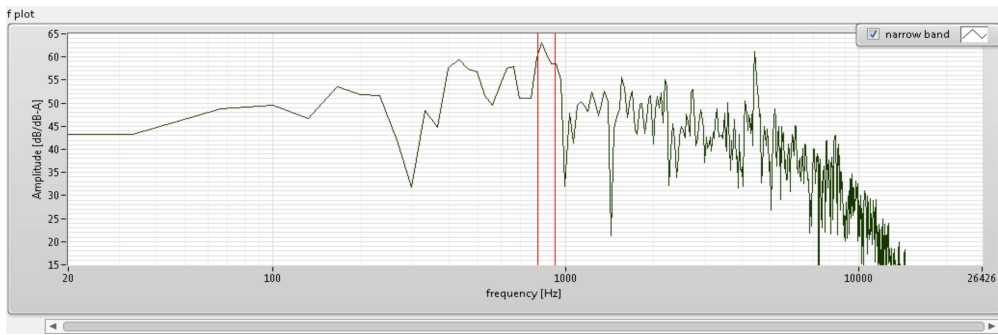


Fig. 5. Noise spectrum of source Z1.



Fig. 6. Source Z2 (industrial fan) – flow $Q = 14\,000\text{ m}^3/\text{h}$, diameter 1 m, frequency range 230–250 Hz.

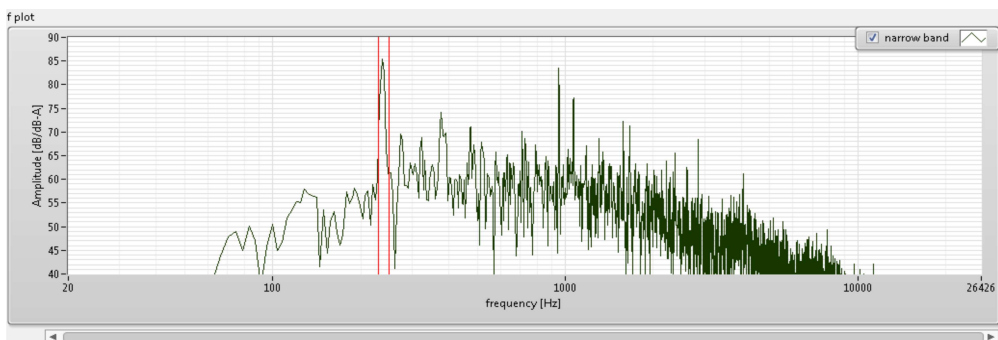


Fig. 7. Noise spectrum of source Z2.



Fig. 8. Source Z3 (industrial fan) – flow $Q = 120\,000\text{ m}^3/\text{h}$, diameter 1.3 m, frequency range 110–120 Hz.

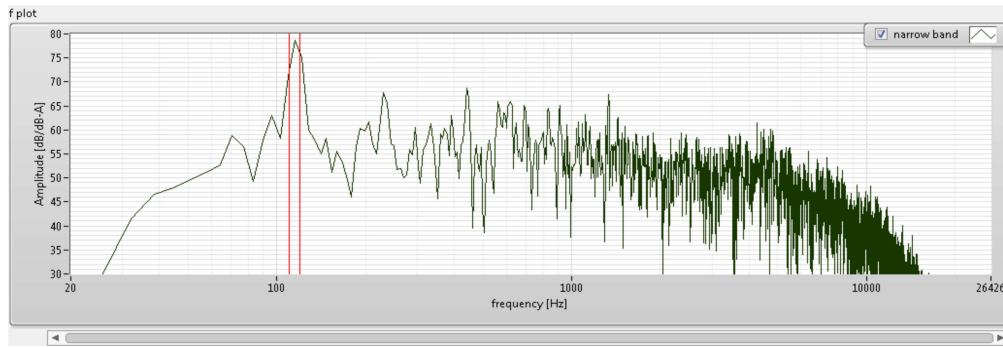


Fig. 9. Noise spectrum of source Z3.

The highest sound power level occurs on the industrial fan (source Z1) which has the highest flow rate. The measurements with acoustic camera have shown that its noise radiation occurs mainly on the inlet side. Other two main noise sources have the sound power levels around 8 dBA lower.

Table 1. Sound power levels L_{WA} [dBA] of the three main noise sources.

Source	Sound Power Levels L_{WA} [dBA]
Z1	122.5
Z2	113.5
Z3	114.9

4.3. Prediction of effectiveness of noise reduction measures

The residential area is located on the east side of the plant and should be protected against noise. Two observation points were located in the residential area and marked on the acoustic map as OP1 and OP2. The noise levels at OP1 and OP2 were respectively 42.2 dBA and 45.2 dBA. Therefore value in OP2 point exceed limit values for residential area during the night (45 dBA). Due to that, the plant was obliged to reduce the noise levels below the limit value.

Following measures for noise reduction has been obtained:

- Acoustic muffler should be installed on the fan inlet – source Z1 (Fig. 10).
- Acoustic barrier on the east side of the plant should be introduced with 8 m height (Fig. 11). The height has been established based on calculations with LEQ Professional. Acoustic barrier was made as concrete retaining wall, thickness 25–35 cm, partly additionally covered with wooden boards.

Based on measurement results the 3D model of the plant buildings and other equipment in the program LEQ Professional has been developed. Furthermore

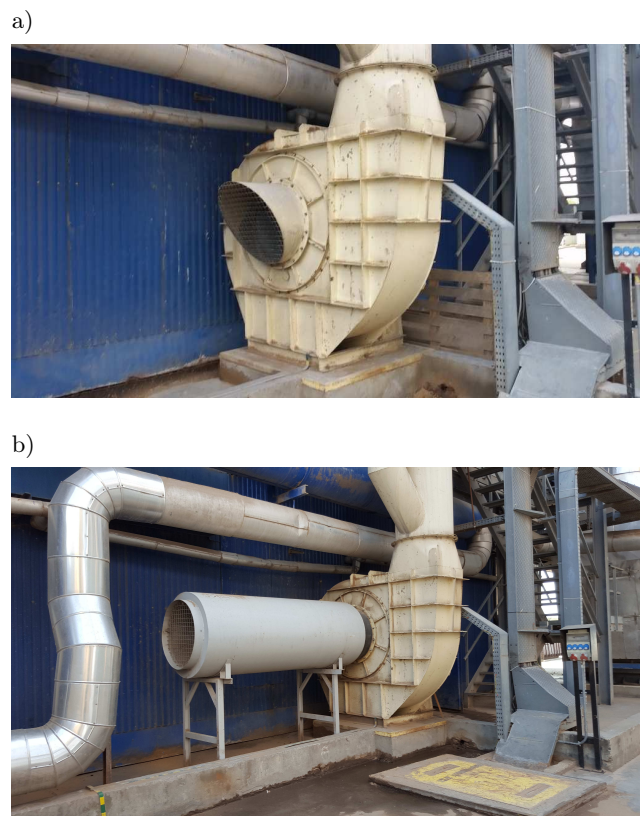


Fig. 10. Industrial fan (source Z1): a) without acoustic muffler, b) with acoustic muffler on the fan inlet.

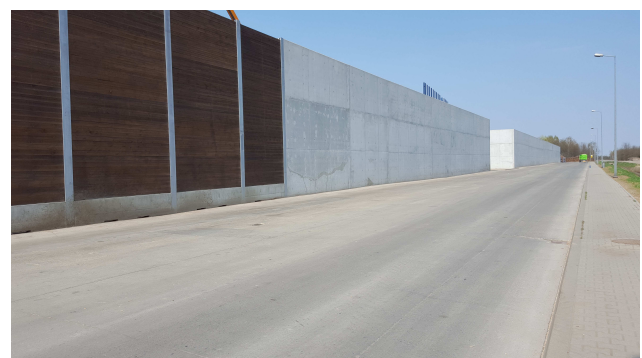


Fig. 11. Acoustic barrier on the east side of the plant.

based on the simulation results the predictions regarding the noise reduction have been done (Table 2).

Table 2. Comparison of predicted noise levels in two observation points in the residential area.

Observation point	Before noise reduction [dBA]	After noise reduction [dBA]
OP1	42.5	37.9
OP2	45.5	40.5

In Table 3 the results of measured noise levels in two observation points (OP1, OP2, Fig. 12) in the residential area have been shown.

In the residential area, where observation points were located, noise limit values are 55 dBA in daytime and 45 dBA in nighttime respectively.

The measured noise level in observation point OP2 where close to the limit value of 45 dBA in the night,

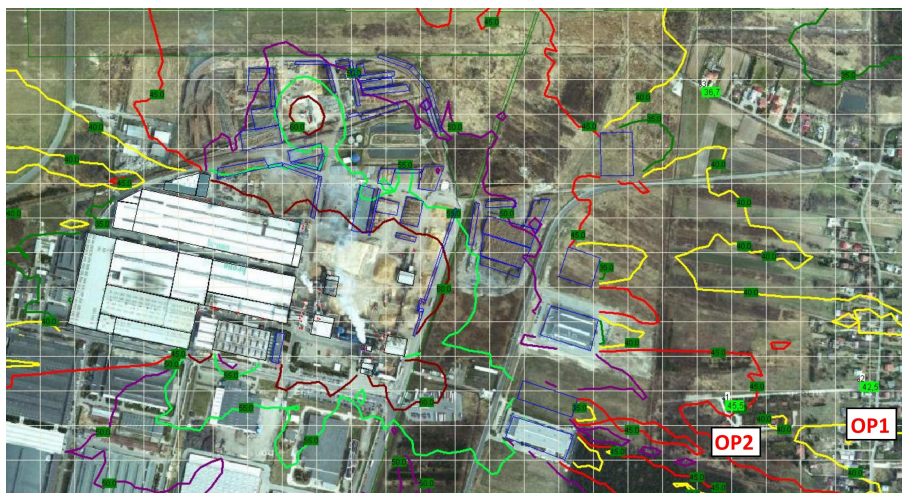
Table 3. Comparison of measured noise levels in two observation points in the residential area (Fig. 9).

Observation point	Before noise reduction [dBA]	After noise reduction [dBA]
OP1	42.2	40.3
OP2	45.2	43.9

but it was required to reduce the noise levels as much as possible in both observations points.

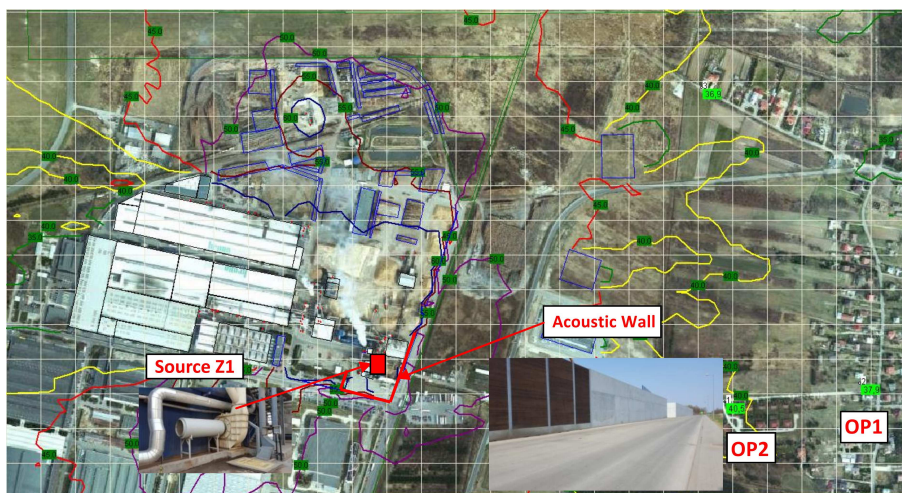
The predicted noise levels in observation points were lower than measured because of relativ high background noise also during the night. In Figs 12 and 13 the acoustic maps before and after introduction of noise reduction measures have been shown.

The noise levels at the observation points in the residential area after introduction of these noise reduction measures meets the limit values prescribed in the regulation (Ministry of the Environment, 2012).



Legend: — -40 dB, — -45 dB, — -50 dB, — -55 dB, — -60 dB

Fig. 12. Acoustic map without noise sources reduction measures.



Legend: — -40 dB, — -45 dB, — -50 dB, — -55 dB, — -60 dB

Fig. 13. Acoustic map with noise reduction measures on the source Z1 and the acoustic wall on the east side of the plant.

5. Conclusions

The methodology for the noise reduction of the industrial plants has been described. Several steps like: main noise sources localization, measurement of the noise emission of the main noise sources, modeling of the environment around the plant and modeling of buildings and equipment inside the plant, simulation of the environmental noise emission from the plant and prediction and measurement of noise levels in the observation points outside the plant, i.e. in residential area need to be done.

The noise sources localization is the key issue to achieve the noise reduction. For that purpose the acoustic camera has been used. Additionally the noise emission of the main noise sources has been established. With the simulation programs, which are currently available, it is possible to establish the noise radiation from the main noise sources to the environment of the plant. The acoustic maps show the influence of noise propagation from main noise sources. For the purpose of the simulation other sources of noise (road, rail, acoustic background) were not included. The study presents acoustic maps obtained before and after introduction of the acoustic measures for noise reduction. In the application example the noise levels at observation points in residential area have been reduced below the limit values with the muffler on the inlet side of the industrial fan and the acoustic wall in the plant.

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