Effective Diagnostic of Local Noise Sources with Acoustic Imaging

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Abstract

In this article, the author described methods of visualizing the acoustic flow and showed how these methods can help scientists understand the complex flow of acoustic energy in a real field. A graphical method for determining the distribution of acoustic waves in a real 3D flow field will be presented. Vector imaging of acoustic events is not possible with the use of traditional metrology applied in pressure acoustics. Based on research using measurements of sound intensity and distribution of vector acoustic field by acoustic orthogonal decomposition method (SI-AOD), the article will present examples of practical applications of these analyses. The described measurement technique, including the method of graphical presentation of results, enriches the knowledge about the mechanism of the flow of acoustic energy stream in real working conditions of the source. The SI-AOD analysis system sets a milestone in the monitoring of sound landscapes and the precise finds noise sources.

Keywords: sound intensity, acoustic imaging, vibroacoustic, noise abatement

1. Introduction

The aim of this work is to present results of experimental investigation a vector fields, shaped in natural conditions by industrial sources of noise; mechanisms and vibrating structures, pipes and HVAC installations systems, transport vehicles, etc. Acoustic intensity measurement technique has been used for the visualization of the energetic sound flow field. When the acoustic field is described by sound intensity, we may understand the mechanisms of propagation, diffraction and scattering of acoustic waves, as energy form of flow wave. Energy distribution images in acoustic fields, connected with the graphical presentation of the flow wave (derived from direct measurements) are a new element in acoustic metrology.

The result of investigation shows the three-dimensional distribution of vector acoustic fields created as an acoustic *intensity streamlines*, propagating *wave shapes* and 3D *intensity isosurface*, all enable a full interpretation of vector phenomena in generated flow field. The visualization of real-live sound fields is useful for understanding the directional radiation of noise sources into three-dimensional space. For that, the vector distribution field will be done of phenomena unknown to us so far. Using own post-processing software (*SIWin*) which are developed for analyses and acoustic image investigated, including method of animation the flow wave (*AnimView*).

Application of the sound intensity method, including the presentation of space vector distribution of acoustic power of noise, may bring new insight into the nature of acoustic field formation in real conditions of working sources. Acoustic conditions in these areas are much different from the theoretical assumptions ascribed to free or diffuse field. It is a frequent occurrence that the sound intensity measurements in real conditions may show great disparity between the theoretical assumptions of the acoustic fields and the actual measurements [1]. The disparity results mainly from simplifications accompanying the analytical methods due to lack of complete data concerning physical properties of an investigated object.

The approach taken here is to use direct measurement sound intensity describing the flow field around two or three-dimensional solid obstacles and illustrate the flow around them as an intensity streamline. The study was conducted to analyze and to improve the comprehension of the mechanism of energy transfer between a turbulent flow and acoustic fields. Aerodynamic results are needed to formulate equivalent source terms while the acoustic results are needed when a coupling procedure based on acoustic boundary conditions is used. It can be expected that through the development of the proper connectivity boundary conditions between the different zones a feedback of acoustic waves from the source region to the propagation region can be incorporated.

2. Visualization of acoustic flow waves

This work present results of investigation the real-live sound or noise field as a form of acoustic energy radiated by vibrating structures and a noise generated around obstacles as a vortex effect in disturbed acoustic wave flow. In traditional acoustic metrology, the analysis of acoustic fields concerns only the distribution of pressure levels but in a real acoustic field acoustic flow energy pressure and acoustic particle velocity (vector value) effects are closely related. Only when the acoustic field is described by sound intensity, we may truly understand the mechanisms of propagation, diffraction and scattering of acoustic waves, as an energy form of flow wave. We can now see what flow wave was hitherto invisible. Energy distribution images in acoustic fields, connected with the graphical presentation of the flow wave (derived from direct measurements) are a new element in noise diagnostic in industrial and living areas. Introduction of these possibilities have greatly changed the approach to examining many unknown acoustic phenomena [2, 5]. This sort of visualization of sound fields is also very useful for understanding of the sound formation mechanism and the transport of acoustic energy in real terms.

The visualization methods to the graphic description of the effects of fluid flow have been developed over the past several years and are widely described in literature [1]. Many of the techniques used in computer graphics flow visualization have been adapted from the traditional methods practiced in wind and water tunnels. Scientific visualization is the use of computer graphics to create visual images, which aid the understanding of this often-immense data set. Visualization system, by serving a dual role as a provider of exploration and exposition capabilities, have become indispensable to the analysis of *Computational Fluid Dynamics* (CFD) modelling results. Generally, a fluid is a rather complex three-dimensional time-dependent phenomenon, however, in many situations, it is possible to make simplifications that allow a much easier understanding of the problem without sacrificing needed accuracy. One of these simplifications involves approximating a real flow as a simple one- or two-dimensional flow, but in many situations the three-dimensional flow characteristics are particularly very important terms of the physical effects they produce [3]. For these situations it is necessary to analyses the flow in its complete three-dimensional character using the velocity components of the flow (acoustic particle velocity components as value of v_x, v_y, v_z to the sound flow, for example).

Acoustic flow imaging is not often enough used in the analysis of noise sources, although, the acoustic energy stream represented by the sound intensity - the vector parameter of the acoustic wave - can directly and relatively easily be measured today using a suitable measuring transducer; the intensity probe. Measured experimentally acoustic wave flow parameters can be used to collect the sound intensity vectors data to visualisation all the wave phenomena occurring in real physical space [2].

The visualization of the distribution of the active and reactive parts of the acoustic field gives the possibility of a full analysis of an acoustic wave. A properly used sound intensity method ensures a chance of measurement of the vector distribution in any place and time of the restricted space, even within a near field.

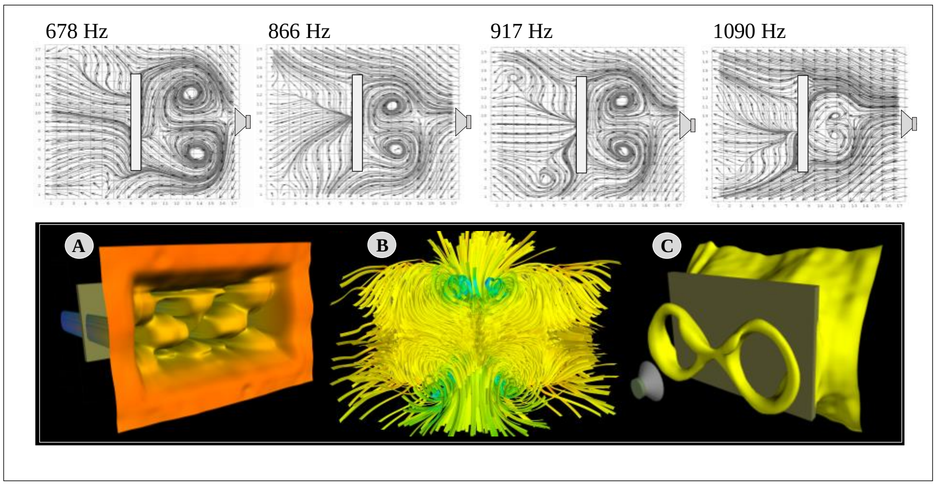

Figure 1. Sound intensity wave distribution around hard rectangular plate (for some selected frequencies): 2D intensity map with vectors (arrows) and SI, 3D shape of wave (A)and SI streamlines in the rear side of plate (B), SI isosurface in the front and rear side (C)

The applied research technique using sound intensity measurements is the vector distribution analysis of acoustic fields generated by sources in the real-live conditions and the creation of spatial visualization of the acoustic wave response to the obstacles in the way of its propagation. Experiments are carried out laboratory research and in industrial conditions using a new method for analysis of the acoustics wave flow as the acoustic energy or noise flux in the real sound field. To the study of the wave acoustics flow, own post-processing program called *SIwin* is used. The distribution acoustic field is presented graphically on the 2D plane or in 3D space as a sound intensity maps, acoustic energy flux lines, shapes of the travelling acoustic wave or as a spatial distribution of intensity iso-surfaces (Fig.1). Based on the measurement data, we also can create animations of the actual forms and wave motions using *AnimWiew* programme [2].

The presented method visualizes the results of acoustics flow and interprets the shapes of the travelling wave, the effects of vortex rotation and the collapse of the wave on obstacles. Even for acousticians, it is so far unknown form of experimental investigations of vector visualization of the flow of events in the acoustic wave like hydrodynamic flows in fluid mechanics. The new testing methods in the acoustic research improve and develop modem diagnostic techniques used to the machinery and mechanical appliances conducted with acoustic methods. They become a very useful tool in optimizing the choice of technical methods for the noise abatements on the workplace.

3. Acoustical imaging and orthogonal decomposition of flow field

The possibility of direct measurement of sound intensity appeared only in the 80s of the last century, when Frank Fahy (1977 [4]) presented intensity probe as a practical measurement tool meets the applicable principles of metrology. Vector analyses give the opportunity to visualize real acoustic wave flows and “watch” the structural effects caused by the wave reaction on obstacles. They are a suitable material for the validation of theoretical analytical and numerical methods built for the study of acoustic sources and acoustic wave-flows. Today we can to *see the flow of an acoustic wave* in the air, similarly to aerodynamic or hydrodynamic flows. Thanks to sound intensity measurement technique and a vector studies on wave motion effects, we may now visualize dynamic phenomena in an acoustic field, just as in other areas of physics and experimental techniques. We can perceive the flow of acoustic stream energy or the shape of an acoustic wave as a disturbance effects on obstacles placed in a field.

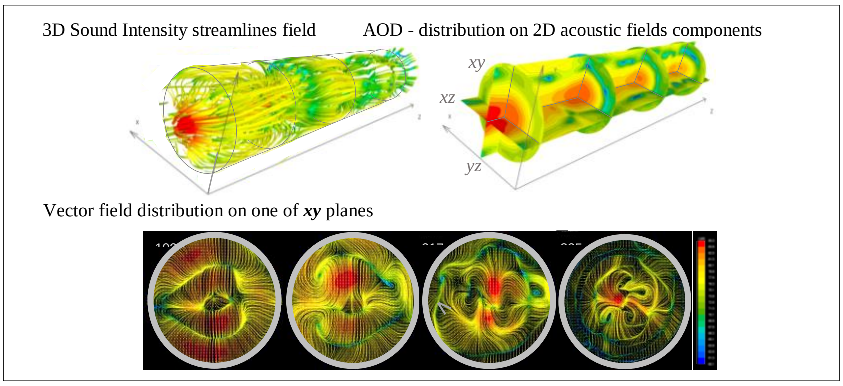

Figure 2. SI-AOD - distribution of vectors acoustic flow field inside circular duct as a function of space, frequency and amplitude

A useful form of analysis for visualization of disturbed acoustic fields is the use of three-dimensional decomposition of vector values represented by the sound intensity. This is a very handy form of analysis. In our research we use a novel tool called orthogonal acoustic decomposition AOD. Spatial SI vectors are divided into three orthogonal component planes in the Cartesian system: *xy*, *xz* and *yz*. After decomposition of the field into 2D images, it turns out that orthogonal components of chaotic wave motion depict deterministic features of chaos. By combining the commonly used frequency decomposition of acoustic field in the range of standard octave frequencies (13, 1/12 octave band) with the SI-AOD decomposition methods, we obtain images containing regular deterministic forms of chaotic wave motion (images of vortices, sources and sinks, rotations, saddles, bifurcating lines - see Fig. 2). It turns out that the SI-AOD method used in experimental studies brings to acoustic analyses the previously unknown possibilities of describing wave motion *in-situ*.

4. Technical acoustic decontamination of noise sources

Acoustic energy distribution images in real-live fields, connected with the graphical presentation of the dynamic flow waves as a vector effect are a rather new element in acoustic metrology. Introduction of these useful possibilities have greatly changed the approach to examining many acoustic phenomena and allows you to effectively use acoustic visualizations to diagnose local noise sources. The sound intensity measurement technique has been used in various studies on theoretical and applied acoustics, greatly simplifying the methods of research. This is because it does not require criteria as strict as in traditional measurements, and the precision of direct measurements in real-life situations does not vary from laboratory experiments. The measurements can be carried out in a near field and in the fields with presence of parasite noise, which is a significant advantage in research. In the paper, experimental studies carried out on real models and structures are documented with graphical records of acoustic fields created by surface sources (radiation of vibrating structures) and the effects of wave interference on obstacles and barriers placed in the flow field.

Direct measurements of sound intensity representing the flow of energy in sound fields has revolutionized acoustical diagnostic methodology. It is now possible to measure the sound power output of individual noise sources of all forms and sizes in their operational environments. ln-situ measurements can be achieved even when sources operate in the presence of other comparable physical powers, a process impossible with conventional acoustic measurement instrumentation. Investigations carried out with sound intensity techniques may be compared against those made by classical methods. This enables us to obtain significantly new information related to energetic acoustic fields in near and far fields, which in turn facilitates the diagnostics of noise sources.

5. Examples of applications for SI-AOD testing of noise sources

Having the technical possibilities of measuring a sound intensity vector in three-dimensional space, it was necessary to work out a proper form for the graphical presentation of the acoustic vector field distribution. The problem involved a way of demonstrating, on a two-dimensional or three-dimensional form of a vector field. In opposite to the classically described acoustical fields with acoustical pressure distributions, the graphical presentation of the acoustic energy flow in real-life acoustic fields as a vectors mapping, can explain many particulars concerning the areas in which it is difficult to make theoretical analysis (direct and near field, vortex flow, effects of scattering on obstacles, reflection on partitions, efficiency of acoustics barrier, etc.).

The paper presents three cases of SI-AOD applications, the results of which are presented in a very brief form. These are only signal possibilities of graphical presentation of research results. More information can be found in other publications from our team.

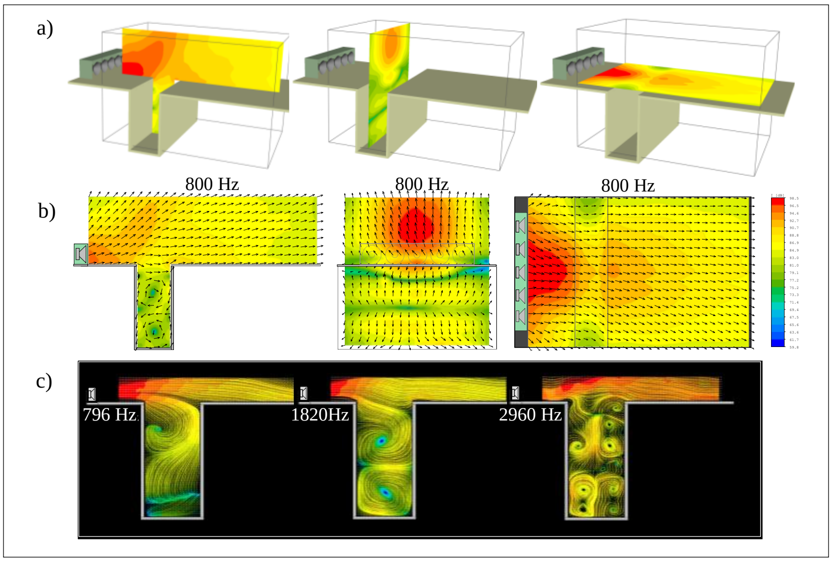

Figure 3. SI flow field for the loudspeaker line array system radiated over a flat plate with rectangular deep cavity: a) - intensity orthogonal maps; *yz*, *xy*, *xz* plane, b) – vectors distributions, c) – characteristic Rossiter modes in the cavity influence on the main flow

5.1. *The influence of a niche on the changes in the flow of acoustic wave*

As the first example of investigation, on the Figure 2 a graphic presentation of spatial distribution the acoustic power flow is show. The analysis of the field includes the vector distributions and the map of the sound intensity flux. It is a certain form of qualitative analysis for stationary fields which consists in a complex evaluation of paths along which the acoustic energy flow. The results of research represent a two-dimensional flow map of time-averaged active intensity space SI vector as a projection on the orthogonal plane and intensity field in the plane is show. The tests concern the vector distribution of the field in an axis of symmetry of the broad-band 5 loudspeakers (*line source*) installed in four discriminate environment conditions. Measurements are curry out in third-octave bands and vectors map have been built in the frequency range between 25 Hz and 6300 Hz. On this figure some example maps of one/third octave band result is show. This kind of visualization may involve depicting various acoustic phenomena, depending on the area of interest. The verifying tests using the SI-AOD technique have shown how much cavity influence on the shape of the flow field. Please put your attention on the vortex *feedback reactions* in the niche for some frequency (*Rossiter mode*).

5.2. *Noise radiation to the inside of the ship's cabin*

Reducing noise in ship rooms to the level required by standards is not an easy structural and technological task. Noise in the cabin is a complex process of interaction of structure-borne and airborne noise [5] and in case of exceeding the permissible level the process of its reduction is often very expensive. In the case of technical noise reduction on the finished vessel, it is therefore necessary to clearly indicate the local element of cabin equipment, from which changes the optimisation works should be started. From the research presented fragmentarily in Figure 4 this is clear that the wall with windows is this element, so the correction works should be started from changing the window construction for liquidation of local sources of noise radiation. Only SI-AOD can effectively diagnose noise from so small local sources.

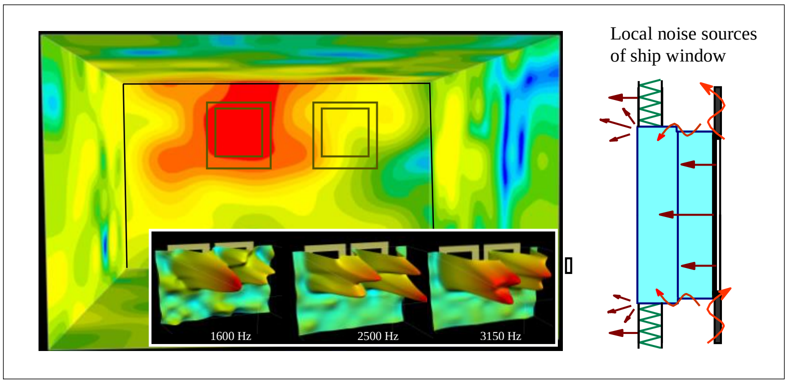

Figure 4. Searching for local noise sources in the ship's cabin using the acoustic imaging

5.3. *Noise optimisation of the electric motor prototype*

The acoustic visualization of the noise generated by an electric motor is another example of effective applications of the SI-AOD research results. The motor prototype was to be subjected to acoustic optimization. It was to be particularly quiet. Figure 5 shows - very fragmentarily - the results, which clearly indicate the mechanism of noise radiation and the local structural elements of the engine, which are its sources.
On this small fragment of the research results one can also appreciate the advantages of the SI-AOD technique.

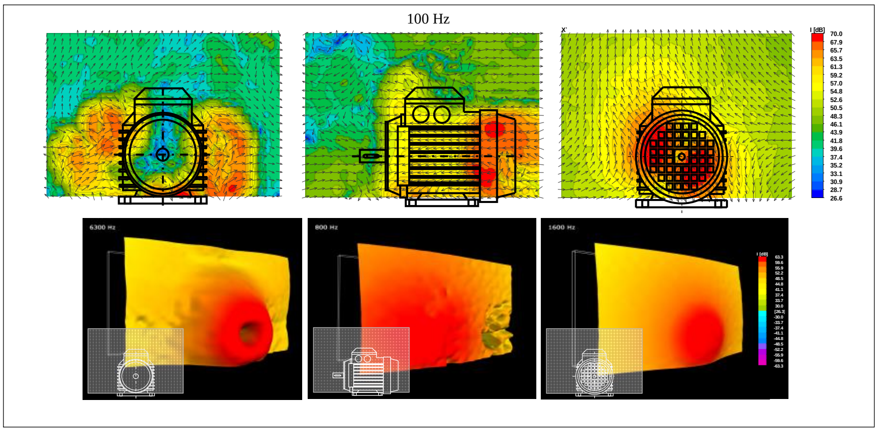

Figure 5. Diagnosis of local sources of noise generated (for f = 100 Hz) by elements of an operating electric motor

6. Conclusions

Main advantages of the research carried out with the application of a SI-APOD technique consist in the fact that the noise measurements taken refer to energy dependencies of the field. As it has been pointed out, this technique is much more effectively than classical methods e.g. to verify the theoretical methods of field modelling with check-up measurements taken in real conditions.

The tests of the acoustic energy flow and presentation of the results in a graphic form shows, that the wave distributions in real acoustic fields can explain many, concerning in the areas for which it is difficult to make theoretical analysis (direct and near field, effects of scattering, shielding area, *etc*.). Described investigation can enrich the knowledge of the scattering effects and influence of environment conditions on formation of noise sources. Direct energy analysis of acoustic fields was not possible earlier because the classical pressure acoustic used a scalar element of acoustic waves. Only when direct measurements of sound intensity became possible, could the wave distribution be analysed in the form of wave acoustic energy transport.

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