IMAGE OF ACOUSTIC ENERGY FIELD RADIATED IN 3D SPACE BY ELECTRODYNAMIC LOUDSPEAKER

PACS: 43.58.Fm

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ABSTRACT
The aim of this work is to present results of experimental investigation a vector field, produced by an electrodynamic loudspeakers (for one, two and five loudspeakers) working in real conditions. The acoustic intensity measurement technique has been used for the visualization of this kind of sound field. The result of investigation shows the distribution of vector acoustic fields created by working loudspeaker as an acoustic *intensity streamlines*, *propagating wave shapes* and *intensity isosurface*, and all enable a full interpretation of vector phenomena in a generated flow field. The visualization of real-live sound fields is useful for understanding the directional radiation of sound emitted by the loudspeakers into three-dimensional space. For that, the vector distribution field will be done using own program (*SIWin*) that are developed for the processing and the visualization investigated results including method of animation the flow wave.

INTRODUCTION

A loudspeaker is a device that converts electrical energy into acoustic energy (electroacoustic transducer). The are a number of ways in which electrical energy can be converted into acoustic energy. All the possibilities for carrying out this function, a relative in practical have become dominate the electrodynamics loudspeaker, transducer with cone driver as an acoustic radiator. Most practical loudspeakers are systems comprising multiple transducer/radiator subsystem, each of which radiates a portion of the audio-frequency spectrum.

The loudspeaker is widely used in many application areas as audio reproduction, telecommunication equipment, active noise control and active noise reduction. The determination of electrodynamic loudspeaker characterization has become important in the analysis and design process for loudspeaker systems manufacturers. In considering the behaviour of a loudspeaker, it stands to reason that we need performance parameters with which we can evaluate the effectiveness of a specific device for an envisioned use. There are many performance areas in which loudspeakers differ in significant ways, including on-axis response, bandwidth, directivity, distortion, and maximum acoustic output. Unfortunately, there are a number of different formats for presentation of loudspeaker performance data. Before attempting to interpret such data, it behoves us to develop some general concepts of loudspeaker performance.

This area of loudspeaker design has a major impact on a loudspeaker ultimate performance, and it is this portion of the design process that is most frequently short-changed. In addition to the required technical expertise, a loudspeaker designer should have the capability of subjectively evaluating a performance – critical listening – and that the final determinate of a loudspeaker's success will almost that there are always objectively observable phenomena that correlate with subjectively preferences. Very large number of objective elements must be accounted for in order to fully characterise the performance of a loudspeaker. This subject is covered in grater depth in collection of loudspeakers technical characterisation value given by producers.

The aim of this work is to present results of investigation the real-live sound field radiated by a loudspeakers as a form of acoustic energy flow in the environment. In traditional acoustic metrology, the analysis of acoustic fields concerns only the distribution of pressure levels (scalar variable) but in a real acoustic field both acoustic pressure and acoustic particle velocity (vector value) effects are closely related and describe the acoustic intensity stream of energy. Only when the acoustic field is described by sound intensity may we truly understand the mechanisms propagation, diffraction and scattering of acoustic waves, as an 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. Introduction of these possibilities have greatly changed the approach to examining many acoustic phenomena. This sort of visualization of sound fields is also very useful for understanding the directional radiation of sound emitted from loudspeaker. The knowledge of the directional features of the sound fields radiated by a loudspeaker is an essential characteristic of any audio system. The picture is made much more complicated by the fact that we hear not only the direct sound produced by a loudspeaker, but also the reflections caused by interactions between the loudspeaker and the acoustic environment in which we are listening.

VISUALIZATION OF ACOUSTIC FLOW WAVES

The visualisation methods to the graphic description of the effects of fluid flow have been developed over the past several years and are described in literature [1, 2]. Many of the techniques used in computer graphics flow visualisation have been adapted from the traditional methods practised in wind and water tunnels. Scientific visualisation is the use of computer graphics to create visual images, which aid the understanding of this often-immense data set. Visualisation system, by serving a dual role as a provider of exploration and exposition capabilities, have became indispensable to the analysis of *Computational Fluid Dynamics* (CFD) results [3, 4].

The study of sound flow visualisation is rather seldom in the acoustical practice. To day, flow motion as the acoustic particle velocity may be measured experimentally using intensity probes, which can be used to collect the sound intensity vectors data to visualisation all the wave phenomena occurring in real physical space [5].

Generally, a fluid is a rather complex tree-dimensional time-dependent phenomenon – v=(x, y, z, t). In many situations, however, it is possible to make simplifications that allow a much easier understanding of the problem without sacrificing needed accuracy. One of there simplifications involves approximating a real flow as a simple one- or two-dimensional flow. In many situations the tree-dimensional flow characteristics are particularly very important terms of the physical effects they produce. For there situations it is necessary to analyse the flow in its complete three-dimensional character using the velocity components of the flow (acoustic particle velocity v_x ,v_y , v_z to the sound flow, for example). A properly used intensity method ensures a chance of measurement of the vector distribution in any place of the restricted space, even within a near field.

Examples in the paper illustrate how the application of the sound intensity measurement may help solve the practical problems of acoustic diagnostics of radiation characteristic for electrodynamic loudspeaker. In the experimental measurements, graphical methods presented the real-life vector distribution in a 3D flow wave field. Traditional methods of acoustic metrology, based on acoustic pressure distribution, did not offer such possibilities.

METHOD OF RESEARCH AND RESULTS

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.). Proposed graphical analysis of the field may include a picture of *streamlines* of the sound intensity flux, *shape of acoustic wave* or *intensity isosurface*.

Many papers have discussed single or multiple loudspeakers arrangements for sound image but mostly in 2D plane. The aim of this work is to present results of experimental investigation a vector field in air, produced by multi-loudspeakers arrangements to achieve precise and stable sound image in the 3D space. For illustrating results, intensity distribution fields produced by electrodynamical loudspeakers are measurement and graphically illustrated using intensity techniques to different method of acoustic flow visualization. Own software (*SIWin*) are developed for the postprocessing and the visualization investigated results.

Sound intensity measurement involves determining the sound pressure and the particle velocity at the same position simultaneously. In the general case measurement of sound intensity require the use of at least two transducers. The conventional technique employs two matched condenser microphones (*p-p* method) or alternatively combining pressure transducer with a particle velocity transducer (*p-u* probe). However, a micro machined particle velocity transducer called the *Microflown* has recently become available [6], and an intensity probe based on this device in combination with small pressure microphone (0,1 inch) is now in commercial production.

In this section the spatial distribution of radiated acoustic energy by the loudspeaker are examined. The visualization of sound intensity distribution produced by a loudspeaker is performed using the acoustic intensity fixed point measurement technique. This technique, using the 3D sound intensity miniature size probe (*Microflown*, type USP) and the frequency real-time analyser Norsonic RTA-840, consists in measurement the sound intensity at different points on a parallel surface at certain distance from the loudspeakers. Taking account of practical criteria, a measurement grid dividing of cubic shape sub-area forming a space matrix measurement points (x, y, z) was chosen. Whit this testing technique, a pink noise signal is applied to the loudspeaker. Pink noise is a random signal that contains equal energy for each unit of logarithmic frequency. The signal from the tested loudspeaker is applied to a series of band-pass filters of constant percent-octave bandwidth (1/3 and 1/12 octave bands), each of which is tuned to a different band centre, and the averages output level of each filter is displayed. The display represents, within the limitations of the amplitude and frequency response of the loudspeaker.

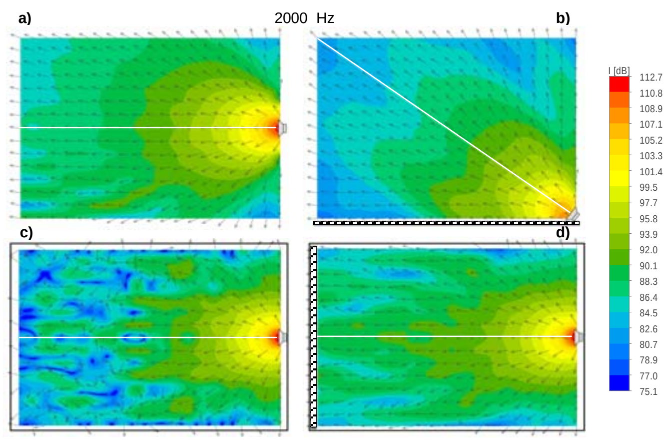

Figure 1. Distribution of the flow field for loudspeaker radiated into a four discriminate environment conditions: a) free field, b) half-space, over the hard plate, c) into the interior with hard walls, d) while the back wall absorbs the sound

As the first example of investigation, on the figure 1 a graphic presentation of spatial distribution the acoustic power flow is show. The analysis of the field include the vector distributions and also 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 vector as a projection on the "xy" 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 loudspeaker installed in four discriminate environment conditions. Measurements are curry out in third-octave bands and vectors map have been build in the frequency range between 25 Hz and 6300 Hz. On this figure as an example, only for 2000 Hz, one/third octave band result is show. This kind of visualization may involve depicting various acoustic phenomena, depending on the area of interest

The next experimental results given in figures 2 and 3 deals with the measurement of sound intensity vector field of a two and three loudspeakers (diameter 13 cm), mounted in a rigid baffle and radiated into free field. The acoustic radiation from loudspeakers in the rigid wall is a good model for studying a loudspeaker radiation. The sound intensity field of a loudspeaker driven by a continuous pink noise excitation has been studied. The partly results of the measurement test on presented figures in the different geometrical form of wave flux can be found. On the two figures 2 and 3 we show the vector maps and intensity streamlines as an acoustic energy flow. The acoustic intensity measurement technique has been used for the visualization of the sound field consider a loudspeaker mounted in a rigid baffle radiates the sound uniformly in all directions and behaves like a point source. The sound intensity falls as axial direction z increases.

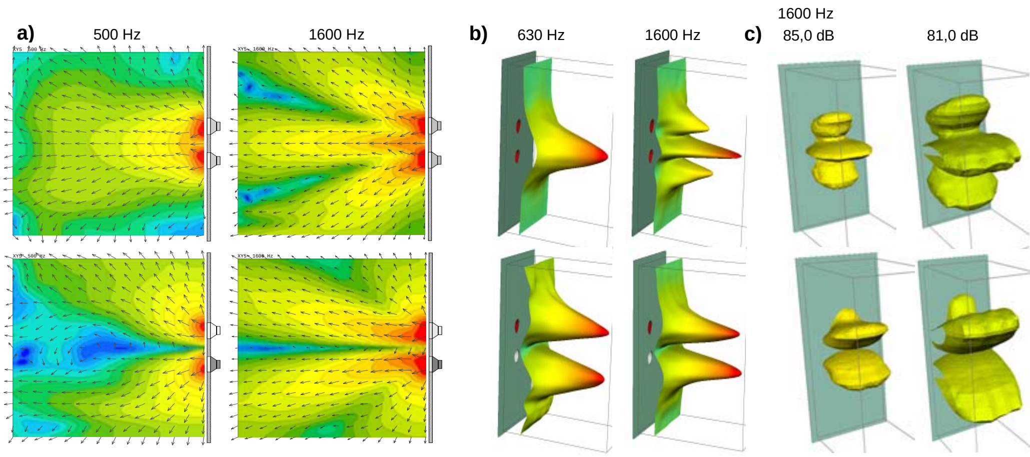

Figure 2. Distribution example of flow field of 2 loudspeakers mounted in a rigid baffle and radiated in different phase condition; upper row – loudspeakers working in phase, bottom row – one of the loudspeakers working out of phase - 180° : a) intensity map in 2D plane, b) shape of wave in space close to the plate, c) intensity isosurface

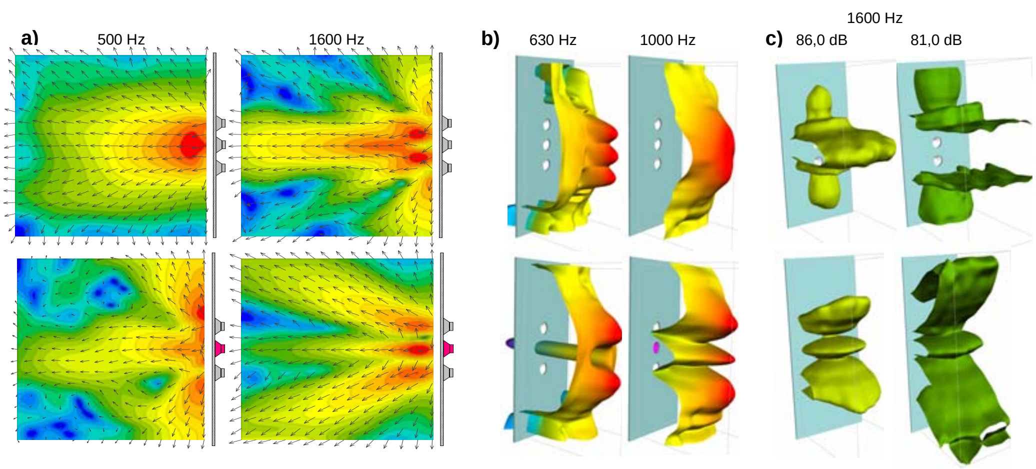

Figure 3. Distribution example of flow field of 3 loudspeakers mounted in a rigid baffle and radiated in different phase condition; upper row – loudspeakers working in phase, bottom row – one of the loudspeakers working out of phase - 180°: a) intensity map in 2D plane, b) shape of wave in space close to the plate, c) intensity isosurface

The next example presents an experimental study of sound intensity stream flow over a flat plate with rectangular deep cavity (0,2 wide and 0,5 m deep). The tests concern the vector distribution of the field excited by traveling incident wave coming from the loudspeaker line array system. In the line array, individual radiators five of complete loudspeaker arranged in a straight line (a sound column), have relatively narrow vertical radiation patterns, which vary strongly with frequency. As attractive as same of the performance characteristics of line arrays may be, they all have inherent limitations. First, the directivity advantages of a line array are present in the vertical plane (along the length of the array) only. The horizontal directivity of a line array is only as good as the performance of the individual devices used to form the array. Secondly, line arrays are made up of discrete elements, as opposed to a continuous line source. This periodicity exacerbates problems with null and lobes.

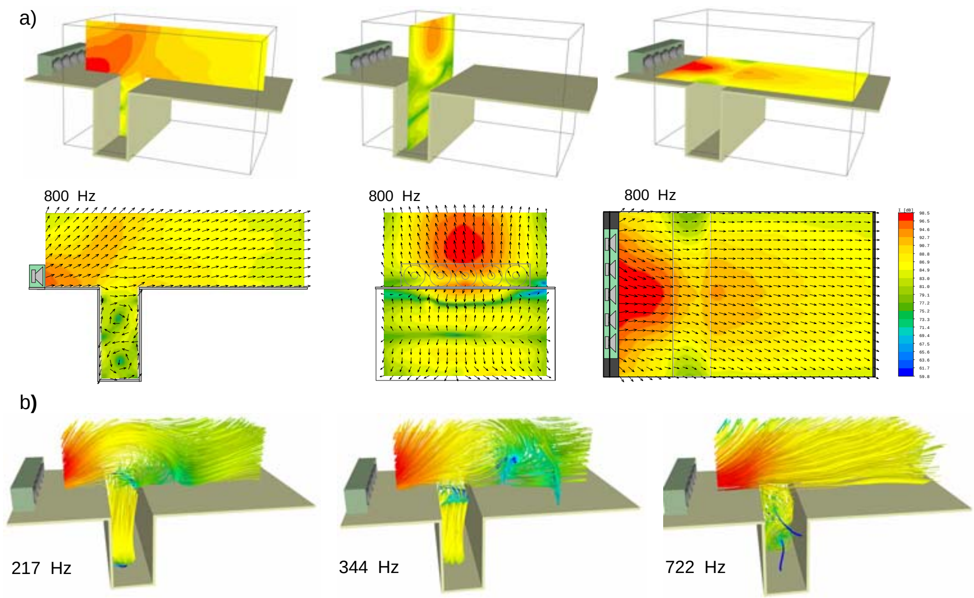

Figure 4. Distribution of flow field for the loudspeaker line array system radiated over a flat plate with rectangular deep cavity (0,2 wide and 0,5 m deep): a) intensity map and vectors in the selected plane, b) intensity streamlines in 3D space (only half of the space is shown)

Figures 4 shows a fragment of these studies as a sound intensity field distribution on the plane (a) and also, as streamlines in three-dimensional investigation space(c). The verifying tests using an intensity technique have shown how much cavity influence on the shape of the flow field. Please put your attention on the vortex effects in the niche for frequency 800 Hz.

CONCLUSIONS

Main advantages of the research carried out with the application of a sound intensity technique consist in the fact that the measurements of loudspeakers radiation taken refer to energy dependencies of the field and that they can be carried out in real conditions. As it has been pointed out, the presented advantages of a sound intensity technique may be used in investigation of loudspeaker characteristics because 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 particulars, 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 a environment conditions on formation of acoustic energy radiated by the loudspeaker installed in real conditions. It is a certain form of qualitative analysis for stationary fields. Direct energy analysis of acoustic fields was not possible earlier because the classical studies used a converter (microphone) measuring pressure changes, 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.

The studies on vector acoustic phenomena carried out in real-life conditions may be also compared with numerical models of acoustic fields, prepared with commercials software available on the market. Experimental investigations indicate that simplicity applied in simulation numerical models result in serious disparities between theory and real-life data [7, 8]. In such cases the sound intensity studies carried out on physical models may link theory with practice by introducing limits to reductions, so that the simulation reflects real-life physical effects.

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