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The Use of Acoustic Vectors Decomposition of Sound Fields to Vibroacoustic Protection on Ships

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In this paper, numerous examples will be illustrated as principles of applying the sound intensity measurements to practical problems at the noise abatement on ships and offshore constructions. The paper presents the results of transmission loss measurements together with flanking transmission for ship bulkheads and partitions with doors and windows. Investigations carried out with sound intensity measurement techniques will be compared against those made by classical methods. Finally for a few examples, the graphic presentation of spatial distribution of sound intensity vectors risen close to vibrating ship cabin partitions and inside the cabin will be shown in 2D and 3D graphical form. As a result, a two-dimensional acoustic wave flow map of time-averaged active intensity vectors propagated along curved streamlines and a vector perpendicular to measured plane are graphically illustrated. The technique of acoustic vectors decomposition of sound fields described, can enrich the knowledge of the mechanism of acoustic energy flux through ship partitions.

Keywords: acoustic vectors field; sound intensity; ship acoustics.

1. Introduction

One of the basic difficulties in carrying out acoustic measurements in ship spaces is the complex distribution of the acoustic field in the accommodation tested. Acoustic conditions in these areas are considerably different than in free or diffuse field. It is a frequent occurrence that the sound intensity measurements in real conditions show great disparity between the theoretical assumptions of the acoustic fields distribution and the actual measurements (Crocker *et al.*, 1981; Fahy, 1989; Weyna, 1988; 1996). So, in order to describe complicated phenomena going on in real conditions, it is most frequently practiced to use experimental research.

Generally speaking, a larger contribution to the total noise of the ship inside spaces is made by of structureborne noise generated by vibrating bulkheads (Weyna, 1996). However, in many sections of the ship, there may be encountered airborne noise getting into the ship inside. The resulting acoustic processes occur in a wide frequency range and are dependent on operational harmfulness in technological and health terms. From the viewpoint of the technological aspect of the problem, our interest concentrates on the limitation of vibration effects resulting from the type of construction and technique of ship installation fixing. The solution of the problem is vital for the protection of accommodations against noise and creating suitable acoustic climate in ship enclosures.

The so-called sound intensity method (SI) is applied in acoustic metrology, simplifies the technique of measurements in comparison with classical methods. Measurements can be conducted in the near field and in the presence of parasitic noise. The possibility of conducting tests in the area of the near field with external noises present has paved the way to the development of tests carried out in real conditions. Direct measuring sound intensity representing the flow of energy in sound fields has revolutionised acoustical metrology (Fahy, 1989). It is now possible to measure the sound power output of individual noise sources of all forms and sizes in their operational environments. In-situ measure can be achieved even when sources operate in the presence of other comparable powers, a process impossible with conventional instrumentation. In addition, the dominant regions of noise radiation can be located with accuracy, yielding substantial economic and environmental benefits through effective noise control.

The commonly used direct measurement of sound intensity has become an efficient tool for noise abatement on ships. Several ship noise problems have failed to be estimated correctly using conventional research methods. The new technique based on the direct measurement of acoustic power transmitted from each of the partitions into accommodation makes it possible to identify the energy transmission paths through bulkheads, ceiling or floor by transmission of structureborne noise, flanking effects and transmission by "acoustics leaks".

For ship acoustics it stands to reason that sound intensimetry should be more effective than sound pressure measurement when applied to assess acoustic radiation efficiency and sound reduction incidence in the presence of flanking transmission and parasitic noise.

2. Acoustic field inside a ship accommodations

The ship's partitions, characterised by high constructional heterogeneity (partitions made of panels of sandwich structure, walls with windows and doors), are surfaces of heterogeneous distribution of vibrations, and the acoustic power radiated by such a surface source may be determined experimentally. In this case the sound intensity technique is a very useful tool in research of noise abatement on ships.

The SI method, give the possibility to identify the structure borne noise energy transmitted through different parts of vibrating structure and is useful information in the study of the phenomena of the acoustic field inside ship accommodations. The aim of the research is to show the estimation of sound power radiated from this partitions. As a result of investigation a three-dimensional flow map of time-averaged active intensity vectors are illustrated with different graphically methods using acoustic orthogonal decomposition (AOD). Having the technical possibilities of measuring a SI vector in three-dimensional space, it was necessary to work out a proper form for the graphical presentation of the acoustic field distribution measured. The problem involved a way of demonstrating, on a two-dimensional or three-dimensional form of the vector field decomposition.

The research aims at explaining the mechanism of transference of structureborne sound into the surroundings using a graphical presentation of the distribution of space vector of intensity (or power) in the acoustic field created inside cabins in the vicinity of accommodation ship partitions and even in full 3D space. The solution of the problem is vital for the protection of accommodations against noise and creating suitable acoustic climate in enclosures.

The flow of acoustic energy is presented by the intensity streamlines (they are graphically presented as ribbons) shows the way of energy flow in acoustic field. Showing the paths along which it is transmitted may be very useful when the necessity arises to visualise the "shape of noise" radiated by vibrating mechanical structures (machines, vibrating heterogeneous plates, equipment's, etc.) and can show their activity also in limited spaces. This is a form of qualitative analysis for stationary fields which consists in a complex evaluation of the paths along which the acoustic energy of a radiating source is transported.

Additionally, the presentation of the shapes of intensity isosurfaces in three-dimensional space was added to bring a new insight into the interpretation of the results of measuring the radiation of acoustic sources acting in limited spaces.

Based on the research with intensity technique and using selected AOD presentation methods, the tests demonstrate some results of vector space distribution of the acoustic field in the area adjacent to the ship partitions. This enables one to obtain significantly new information related to energetic acoustic fields in the vicinity of vibrating ship partitions which, in turn, affect the noise distribution inside the cabin.

3. Ship acoustic investigation with sound intensity method

The measurements described were carried out in real size crew cabins built on the second deck of full scale mock-up superstructure (Fig. 1). The superstructure was built on shore as a ship acoustic laboratory to carry out dynamic research in the conditions close to the real ones. To simulate the excitation from a ship

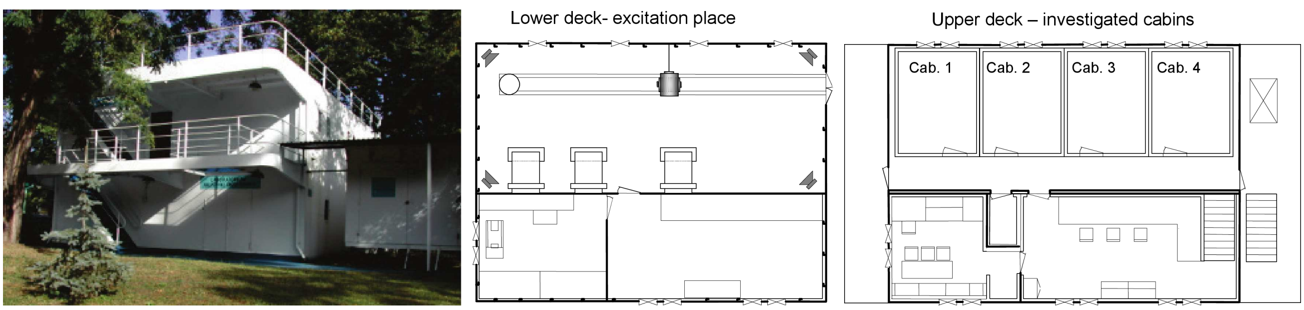

Fig. 1. The full scale mock-up superstructure.

engine (airborne and structureborne noise), an electrodynamics exciter and a high power loudspeakers are used acting on the steel hull under the investigated cabins.

The noise occurring in ship's accommodation comes mainly from structural sounds, emitted by vibrating partitions. Ship's partitions, characterised by high constructional heterogeneity (partitions made of panels of a sandwich structure, walls with windows and doors), are surfaces of complex distribution of vibrations (Fig. 2), and the acoustic power radiated by such a surface source may be determined only experimentally. Especially in this case a SI technique is very useful tool in research.

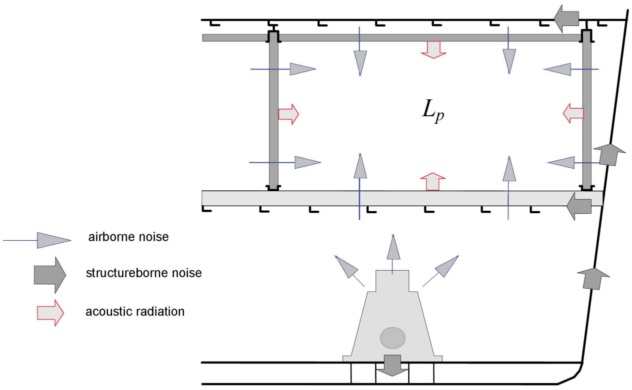

Fig. 2. Transmission of vibroacoustic energy (noise) into ship accommodations.

The measuring equipment included a two-channel real time analyser type RTA-840 (from NORSONIC SA) working with the sound intensity probe "p-v" type NE-216 and the robot system for the probe movement within the region of field determined by the measurement plane. A principal concern of the author was the appropriate presentation of the measured acoustic field distribution so, the intensity vector was analysed in each point of the enlarged measurement grid by measuring the three mutually perpendicular sound intensity components x, y, z. The AOD field was presented as a projection of spatial vector **xy** on the measurement plane in the common form of "arrows". Comparing quantitative distributions of the field in the direction perpendicular to the measurement plane (vectors **z**) against the picture of line distribution of acoustic energy stream, it is possible to read a form of spatial character of the field. Additionally, a graphic analysis of the field may include a picture of streamlines of sound intensity flux. The presentation of acoustic energy propagation by showing paths along which it is transported, may be particularly useful in cases of visualising the radiation of complex acoustic sources and showing their behaviour in restricted spaces. It is a certain form of qualitative analysis for stationary fields, consisting in a complex evaluation of propagation of the radiating source energy. It enables carrying out energy tests for the acoustic field areas in which the phenomena display the acoustic vortex. In such regions the effects of acoustic pressure and intensity are uncorrelated. Some vortex effects appear, and the phase shifts occurring in higher components stimulates additional interference effects. It is mostly the area considered as a near field, but not only.

The suggested research method based on the SI technique in combination with a graphic presentation of the field distribution of acoustic intensity or acoustic power using own postprocessing software (*SIWin*) gives a full range of interpretation possibilities of energy effects and the precautions taken. Also, it makes it possible to choose in an optimal way to noise abatement on ships.

4. Transmission loss of ship partitions

The SI technique is extensively used to measure the transmission loss of partitions as an alternative to the classical method described in ISO-140 which, for measurement of sound transmission loss of panels or walls, is the well-known two-room method (Fig. 3). The main limitation of the classical method consist in using of two reverberate rooms which are separated by the investigated partition and transmission loss is calculate as (Crocker *et al.*, 1981)

$$R' = L_{p1} - L_{I2} + 10\log\frac{S}{A} \quad [\text{dB}], \tag{1}$$

where the S – surface of wall and A – acoustic absorption of receiving room.

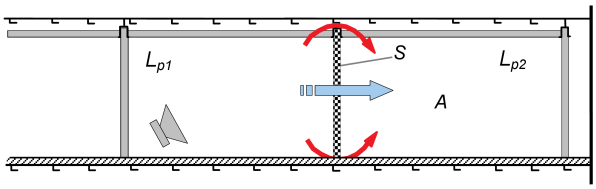

Fig. 3. Measurement method of bulkhead transmission loss.

In the context of measurement of transmission loss the main advantage of the SI method over the classical two-room one is that measurements can be made with only one reverberate room consuming much shorter time and using the simple equation (Weyna, 1995)

$$R' = L_{p1} - L_{I2} - 6 \quad [\text{dB}], \tag{2}$$

where L_{p1} – the average sound pressure level in cabin 1, L_{I2} – the average sound intensity level near the wall in cabin 2.

Another important advantage of the SI method is that a graphic presentation of spatial intensity vector distribution in the near field enables the identification of leaks and the transmission of energy through different parts of composite panels (Weyna, 1993c). For the transmission loss measurements with the SI technique we applied the scanning method of measurement, moving the probe over the investigated surface. The distance between the probe and the partition has been not critical, so scanning the probe at nearly constant distance is preferred to measurements at different fixed points. The measurement time is shorter than with the conventional method. By scanning the sample to measure the radiated energy, it is important to determine the exact sound intensity. Therefore the measurement condition must be chosen after the introductory measurement and of the "*pI*" field indicators according to ISO DP-9614.

The transmission loss measurement results of in the in-situ conditions by using both the SI and classical methods are presented in Fig. 4, in which subst antial differences can be observed. Since the same kind of differences has also been observed (Crocker *et al.*, 1981) in testing transmission loss of homogeneous partitions, we can ask a question: which of the results evaluates the insulation properties of measured ship partition is better? In fact it is only the SI technique that makes it possible to measure the direct net transmitted power by the partition, and additionally only this method is in compliance with transmission loss definition.

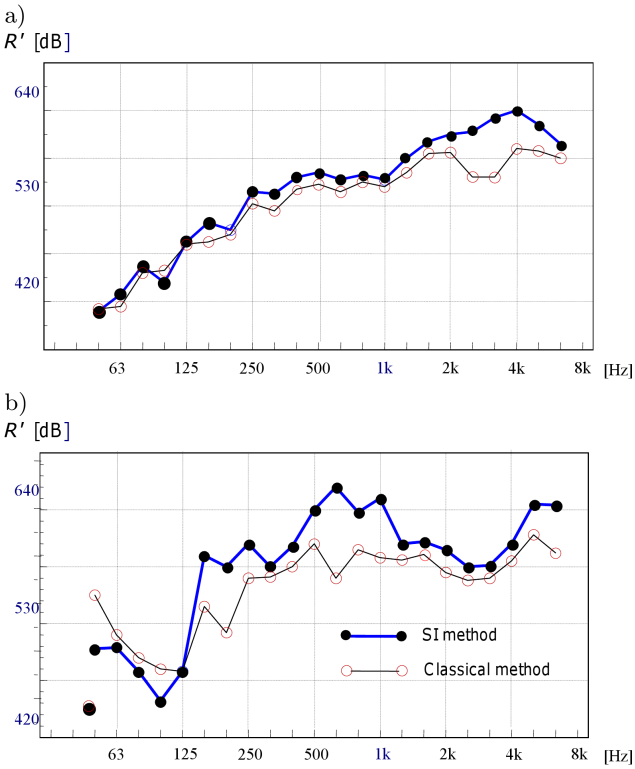

Fig. 4. Comparison between transmission loss of the wall with cabin door (a) and wall with window (b) measured with classical and intensity method.

On the Fig. 5 we can show in 3D form how the noise as the acoustic energy effect passed over the shipboard wall of the crew cabin. It can clearly noticed how much more energy flows through the leaks in the technological connection wall panels.

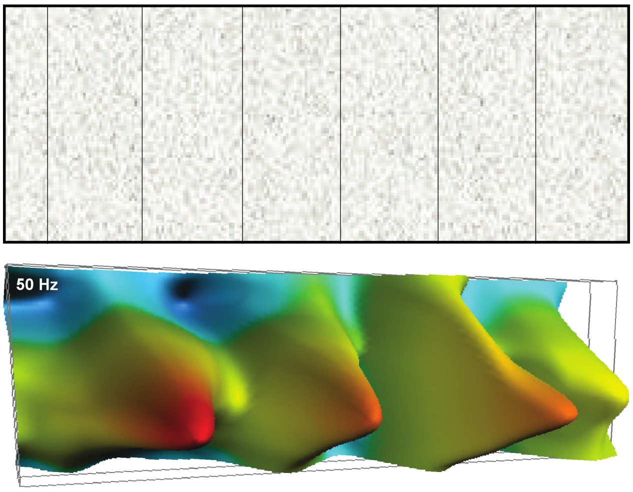

Fig. 5. Noise passed over the shipboard wall of the crew cabin as the acoustic energy effect.

5. Acoustic radiation efficiency from ship partitions

For the ship accommodation partitions, in lack of theoretical estimates, experimental procedures have to be developed to measure the radiation efficiency coefficient σ (Weyna, 1993a; 1993b). In classical method the radiation efficiency describing as $10\log\sigma$, is calculate from

$$10\log\sigma = L_p - L_v + 10\log\frac{A}{4S} \quad [\text{dB}], \qquad (3)$$

where L_v – the average surface velocity level of vibration structure.

Recently a new measurement techniques have been developed to describe the characteristic of radiation efficiency. The sound power radiated by structure can be described by sound intensity measurement, and the surface velocity may be measured with accelerometer, optical or ultrasonic transducers. According to the Eq. (3), the radiation ratio can be now expressed as a simple equation:

$$10\log\sigma = L_I - L_v \quad [\text{dB}], \qquad (4)$$

where the L_I is sound intensity level calculated as a mean value of the scanning of the intensity probe just behind the radiated partition and L_v is the average level of velocity on the vibrating structure.

By using the SI method to measure radiated sound power directly, it should also be possible to determine the amount of radiated sound power from different small parts of the test partition. The scope of this research is experimental determination of the radiation for the same different type of bulkheads, ceiling and ship floors using a conventional method of measurement and sound intensity technique (Fig. 6).

The detailed experimental tests show that for ship space the wall with windows is a dominating source.

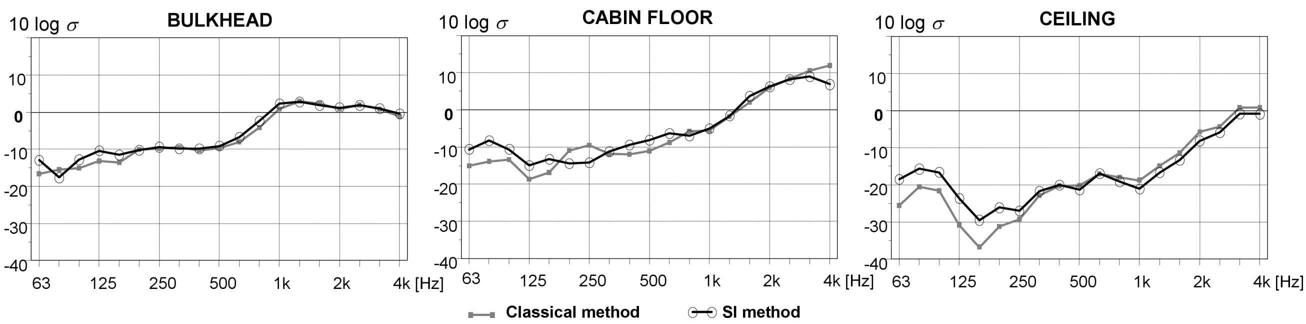

Fig. 6. Radiation efficiency characteristics for different ship's partition measured with classical and SI method.

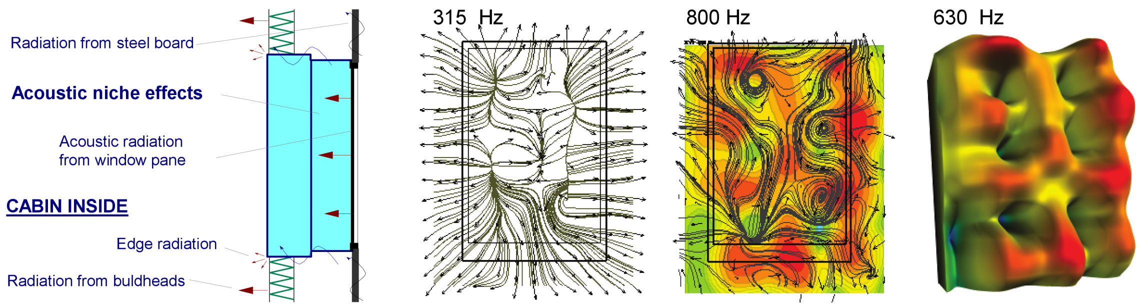

Fig. 7. Graphical form of visualization of acoustic radiation of the cabin windows.

The vibration level of side plating to which the window frame is fixed is many times higher than inside wall vibrations, and the window stimulated to vibrate is a source of major noise threat to the cabin. The excitations of a niche formed by the window box recess additionally causes some disturbances in the formed acoustic field (so cold "acoustic niche effect", see Fig. 7).

Similar research results as the SI streamlines distribution in the cabin with window are presented in Fig. 7. They show the acoustic energy flux on the 3D space of cabin. The vector analysis of the field within tested frequencies makes it possible to estimate which parts of the window construction have the biggest share in radiation, and how a "niche effect" influences on the process of rotation formation inside cabin. The picture of a field shape show in a form of line distribution of acoustic energy streamlines completes the vector analysis.

The entrance door of cabins built in the corridor partition are the acoustically weakest element in the cabin partitions. Satisfactory door insulation can be achieved depending on the insulation of the door wing and proper tightness along the whole frame. But even the smallest leaks can drastically lower the acoustic insulation in higher frequencies. Small leaks can be efficiently localised by a vector presentation rather than by mechanical inspection. In the course of experiments such a SI method was applied in testing the cabin door.

During measurements, the source of excitation operated outside the door in the corridor while the measurements were carried out inside the cabin. Intensity measurements were conducted on the surface parallel to the wall with door. Vector field distribution in the form of vectors and shape of wave lying on the measurement surface, present the acoustic energy radiation from the door inside the cabin, are shown in Fig. 8. For selected frequency ranges the comparative results can easy detect any leaks on the door wing and estimate how the energy flow through the slight slit acts on the field in the door region. Both the leaks on the door frame and the presence of the niche around the frame will create rotational shapes of the acoustic field in the vicinity of door. This is evident in both the higher and lower regions of frequency.

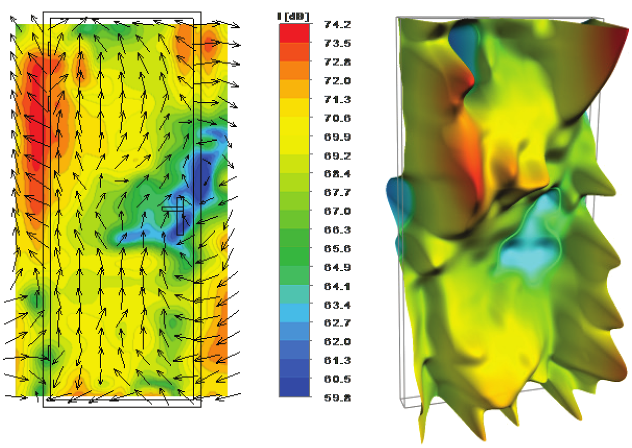

Fig. 8. Acoustic vectors field distribution close to the cabin door.

Another one application of the sound intensity technique is demonstrated on the investigation of a ship "floating floor" construction. The presentation of noise distributions of real acoustic fields in the area close to the cabin floor can explain where are the week place of this construction from acoustic point of view. Three dimensional pictures as a shape of transported waves clearly explain how the noise is coming inside and estimate of all local radiation sources and regions of vibroacoustic bridges through which the radiated noise is passed over the floor construction (Fig. 9).

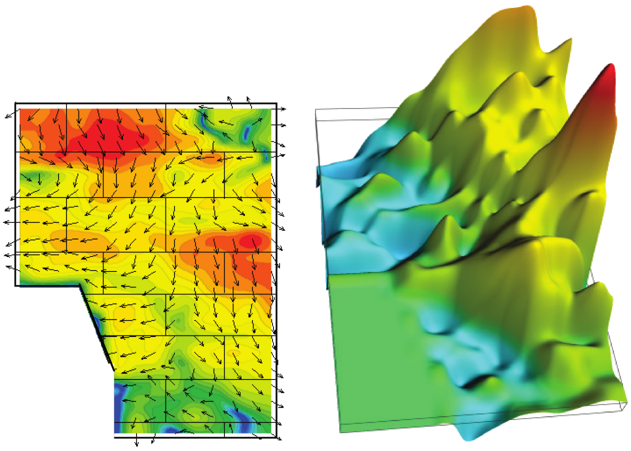

Fig. 9. Noise radiation into cabin from "floating floor".

All the investigations give rise to conclusion that in the ship accommodation with structure borne noise radiating inside, the streamlines of the active intensity vectors have a rotational nature in all cabin space. This nature acoustic field is born mainly by the specific radiation from the window boxes and also by the reflection waves and interference phenomena between several coherent sources (vibrating cabin partitions: bulkheads, floor and ceiling).

6. Conclusions

The sound intensity measurement may be seen as one of the most important developments in ship acoustics and can be applied in various investigations such as in-situ determination of the acoustic power generated by ship mechanisms and equipment of crew cabins under operational conditions. One of the main advantages of the sound intensity technique is possibility of identifications of the structureborne energy (or acoustic power) transmitted through different parts of the cabin partition and the acoustics weak points on the investigated partitions. This would be not possible to see in a classical method.

It is very important that the research carried out with the application of a SI technique consists in the fact that the measurements taken refer to energy dependencies of the field and that they can be carried out in real conditions. As pointed out before the presented advantages of the SI technique may be used in acoustic metrology 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 made on in-situ conditions and presentation of the results in a graphic form show that the application of principles of phenomena superposition in theoretical methods of acoustic field modelling should be carried out with great care.

Using the intensity technique with different visualisation method of vector effects as an AOD in real acoustic field, the tests demonstrate the results of research on the space distribution of waves in the crew cabins makes it possible to obtain much more new information about the energetic and geometric form of the acoustic fields in the vicinity of ship partitions and influence on the noise distribution inside the cabin.

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