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RADIATION EFFICIENCY CHARACTERISTICS ESTIMATED BY SOUND INTENSITY METHOD

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Radiation efficiency factor is determined conventionally by a very complicated method and may be carried out only in laboratory condition. Using SI techniques, precise measurements can be made even under in-situ conditions, saving a lot of time in comparison to the classical method. The article presents the application of SI to measure radiation efficiency characteristics for ship cabin partitions (bulkheads, floors and ceilings). Tests carried out with SI techniques using scanning method to measure are compared with those made by conventional method. Based on the near-field acoustic intensity measurements with the fixed point method, the spatial intensity vectors in a plane close to the ship partitions. As a result of such investigation, a three-dimensional flow map of active intensity vectors, together with paths of energy streamlines, is graphically illustrated for one of the partitions.

1. Introduction

The noise is penetrating to the cabins as airborne noise and structure-borne noise. The airborne noise is radiated from the main working machines and is exciting the deck above and transmitted to the region on which possible cabins may be placed. The structure borne sound is generated in the steel structure at all solid connections as structural waves penetrating hull plate and pillars to the upper decks in the accommodation. The flexural wave motion of the deck will also cause flexural wave motion of the bulkheads, because of their strong coupling with the vibrating deck. The sound radiated, however, because of this effect contributes considerably to the several noise in the cabin, especially at low frequencies, where the commonly used bulkheads are generally stronger sound radiators than is the deck. The excited vibrational movements of the accommodation elements (result of structure borne noise cause the sound to be radiated to the enclosed cabin.

For a ship accommodation system one must determine the acoustic parameters wanted as input data for sound transmission prediction methods or for construction information during product development work as well as for ship designers. Because of the complicated ship structures and coupling involved, the determination of acoustic characteristics must be done experimentally. Acoustic investigation carried out directly on board gives rise to a number of technological and organizational problems which practically exclude a possibility of complex studies.

Therefore it is a usual practice that the vibroacoustic properties of the accommodation partitions are tested experimentally using model or mock-up system, that is as near the real ones as possible. From a number of tests it follows that the most effective are the investigations of real size cabins with complete equipment. The tests carried out on real construction make it possible to determine the effect of each partition of cabin on the noise level permeating inside. From the analysis of the phenomena occurring inside the cabin it follows that the noise results from the acoustic radiation transferred by the vibrating floor, bulheads and ceiling (structure borne noise).

The amount of airborne sound, due to structure borne sound transmission, obtained in a cabin depends on the vibrating levels of the lining surfaces, usually expressed as velocity levels, and the radiation properties of the lining, usually expressed as radiation efficiences "σ". When radiation efficiency is used, the radiated sound power from a surface with the area "S" can be expressed as

$$P = \rho_0 c_0 \sigma S \langle v^2 \rangle \quad [\mathrm{W}], \tag{1}$$

where $\langle v^2 \rangle$ — the mean square velocity over the surface and over sufficiently long time, and $\rho_0 c_0$ — characteristic impedance of the surrounding medium air.

The power can also be expressed as a function of the resulting pressure squared and the equivalent absorption area in the room, i.e.:

$$P = \frac{\langle p^2 \rangle A}{4 \rho_0 c_0} \quad [\mathrm{W}]. \tag{2}$$

According to the Eqs. (1) and (2), radiation efficiency described as level value 10 logσ may be determined from the formula

$$10 \log \sigma = L_p - L_v + 10 \log \frac{A}{4S} \quad [\mathrm{dB}]. \tag{3}$$

The radiation factor can be calculated for rigid and homogeneous plates [2, 5], but in the present ship practice (soft and sandwich constructions of partitions) the only possibility is an experimental procedure.

It is well known from the existing theory that the radiation from a finite homogeneous, isotropic plate, excited to free bending vibrations, is partly due to contribution for resonant modes and, partly, a contribution from the forced motion of the plate areas around the excitation points or lines [3]. The measurements should therefore use an excitation method that produces a resonant bending wave field, sufficiently independent of the choice of excitation point or lines. However, when complicated constructions are used, such as the sandwich-type bulkheads or ceiling with a mineral wool core, the theoretical formulas are no longer applicable. For the ship accommodation partitions, in lack of theoretical estimates, experimental procedures have to be developed to measure the radiation efficiency according the formula (3). Until now, this measurement method has been called conventional and the details of the excitation as well as the details of attachments and edge conditions for all investigated partitions are described in [7] and [8].

Recently new measurement techniques have been developed. The sound power radiated by the structure can be done by intensity measurement, and the surface velocity may be measured with accelerometer, optical or ultrasonic transducers, or sound intensity probe. According to the Eqs. (1) the radiation ratio can be now expressed as

$$10 \log \sigma = L_I - L_v \quad [\mathrm{dB}], \tag{4}$$

where the L_I is the sound intensity level calculated the mean value of scanning of the intensity probe just behind the investigated partition.
By using the SI method to measure the radiated sound power directly, it should also be possible to determine the amount of radiated sound power from different parts of the test partition. The scope of this research is experimental determination of the radiation for the same set of different types of bulkheads, ceiling and ship floors, using a conventional method of measurement and sound intensity technique.

2. Description of tests and results

As the conventional method of radiation efficiency measurement is commonly known [1], it will suffice to describe only the sound intensity measurement technique. One should underline, however, that the measurement conditions and excitation methods remain the same for both techniques.

The sound intensity measurements were made with NORSONIC Sound Intensity Analyzing System type RTA-830 together with "$p-v$" type intensity probe. Measuring frequency range covered the range from 63 Hz to 4000 Hz.

The first test was carried out for the total acoustic power radiated by each partition. The scanning method was used, moving the probe over the investigated surface. The scan plane being 0.1 m from the partitions, each partition was divided into sub-areas about 1 m², scanning speed was 0.2 m/s with a distance between scanning lines of 0.1 m. The distance between the probe and the partition has been not critical, so scanning the probe at nearly constant distance is preferred to the measurements at different sub-areas. With the scanning method, the measurement time is shorter than with the conventional method.

When scanning the sample to measure the radiated energy it is important to determine the level of precision of sound intensity measure. Therefore, the measurement condition must be chosen after the introductory measurement and analysis of the *"pI"* field idicators according to description in NORDTEST [6] and ISO Recommendation described in DP-9614 [4].

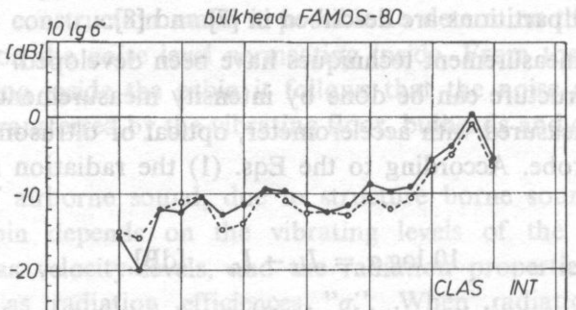

Fig. 1. Comparison of the results for the 80 mm thick, light bulkhead type FAMOS-80 and hard-core, 22 mm bulkhead type CMB-22.

Figures 1, 2 and 3 show the comparative results between both measuring techniques for six different ship accommodation partitions. It must be noticed that, except at lower frequencies, where SI gives higher values, the agreement between the results obtained by

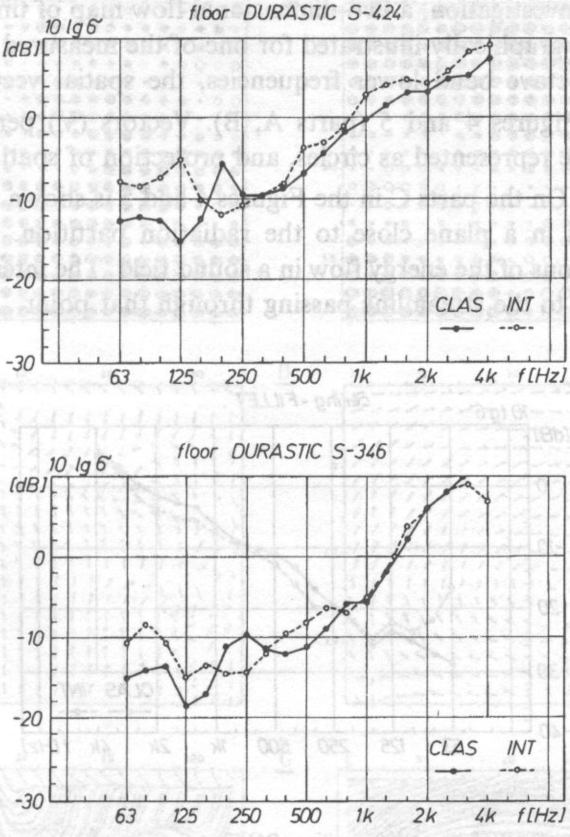

Fig. 2. Comparison of the results for the floating floor type Durastic S−424 on top of Rockwool 200/40 and S−346 on top of Rockwool 150/50.

both methods is good. The agreement is very satisfying over the frequency 250 Hz. Differences at lower frequency could be attributed to the Waterhause correction which should be made on the sound pressure measurements in the classical method.

Recognition of the vectorial nature of acoustic intensity provides very useful information in the study of phenomena of the acoustic field; in further investigation we try to explain the differences between both methods of measurements. In the second test with the intensity technique, the point measurement method was using for a more detailed analysis of the acoustic field in vicinity of the radiated structures. In the point measurements the probe is rotated to measure the intensity vector in tree directions: horizontal ($\overline{H}$) and vertical ($\overline{L}$) parallel to the partition, and normal ($\overline{V}$) to the partition. During this rotation, the acoustical and geometrical center of motion is kept in the same position. The measured grid is 22 by 18 points, with 0.1 m distance between points and 0.1 m from the partition.

As a result of investigation, a two-dimensional flow map of time-averaged active intensity vectors is graphically illustrated for one of the measured partition. For the four chosen 1/3 octave band lower frequencies, the spatial vector distribution is demonstrated in Figures 4 and 5 (parts A, B). Vectors (V) perpendicular to the measured plane are represented as circles, and projection of spatial vector on plane (H+L) as arrows. On the parts C in the Figures 4 and 5 is shown the distribution of energy streamlines in a plane close to the radiation partition. These streamlines indicate the directions of the energy flow in a sound field. The intensity vector at any point is tangential to the streamline passing through that point.

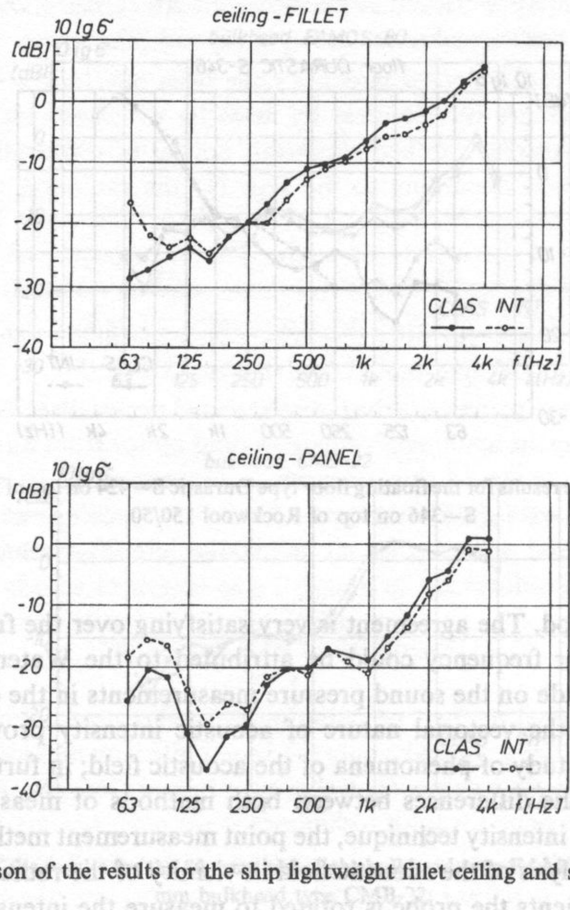

Fig. 3. Comparison of the results for the ship lightweight fillet ceiling and steel, panel ceiling.

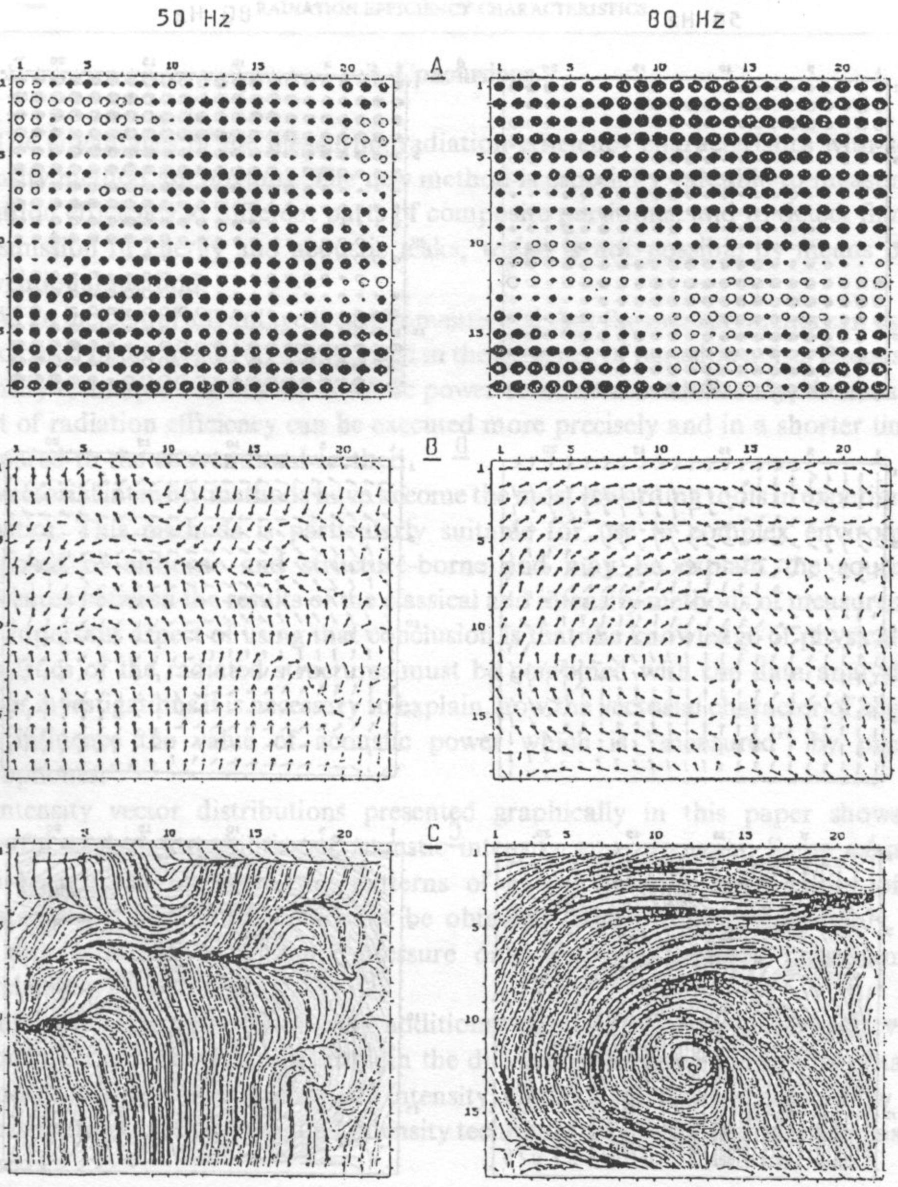

Fig. 4. Intensity vector distribution in vicinity of vibrating floor for 1/3 octave band 50 Hz and 80 Hz. A — vector V, B — vector H + L, C — energy streamlines.

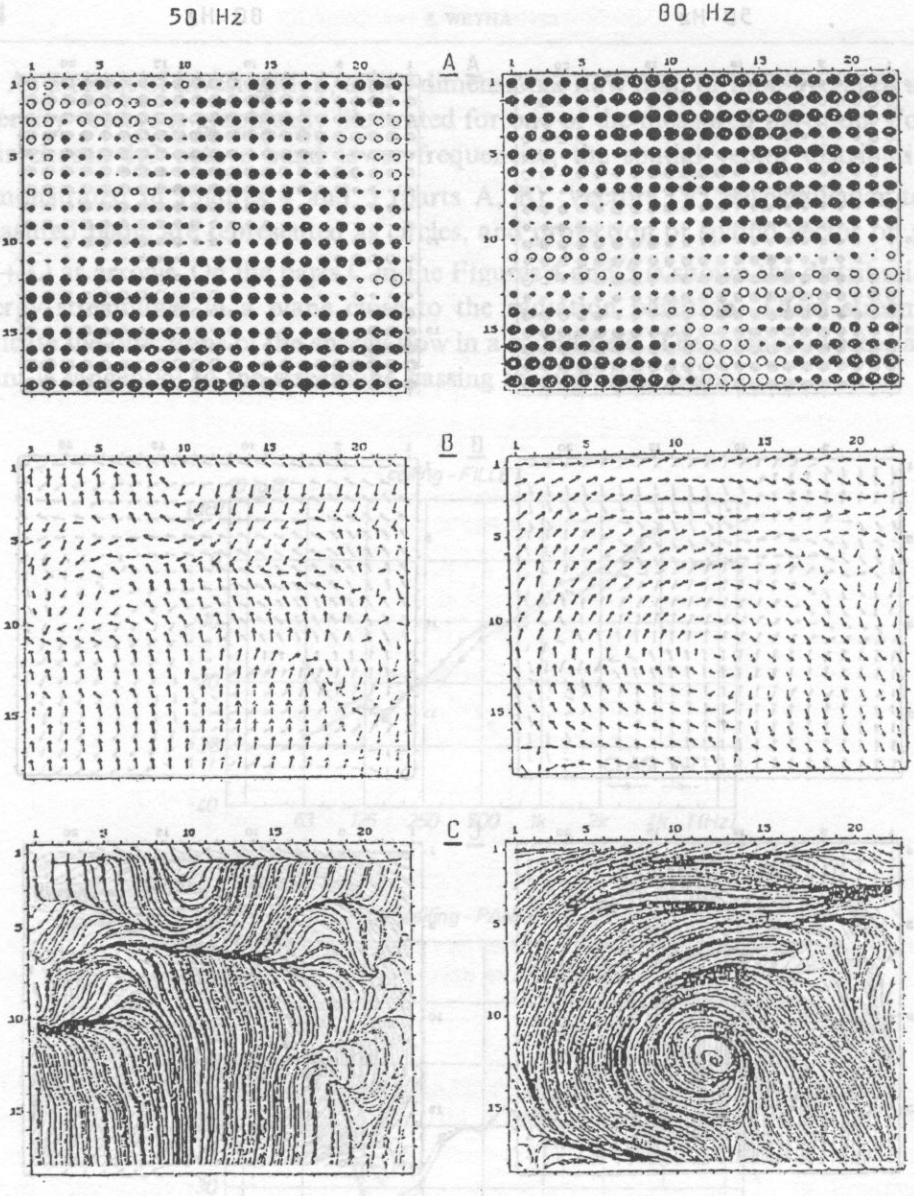

Fig. 5. Intensity vector distribution in vicinity of vibrating floor for 1/3 octave band 125 Hz and 315 Hz.
A — vector V, B — vector H + L, C — energy streamlines.

3. Conclusions

The advantages of the measuring radiation efficiency characteristics with sound intensity method are obvious. The new method is especially valuable to measure the radiation efficiency at different parts of composite partitions, and to detect flanking transmission of energy and acoustic leaks, which is not possible by means of the conventional method.

As an incidental advantage it can be mentioned that the measurements can usually be executed under in-situ conditions and in the presence of parasitic noise. Because the intensity technique enables the acoustic power to be measured directly, the measurement of radiation efficiency can be executed more precisely and in a shorter time as compared to the conventional method.

Vectorial intensity methods have become the most rewarding tools in experimental acoustics. This methods is particularly suitable for use in complex environment composed of airborne and structure-borne and may be explain the source of differences between the results of the classical and intensity methods of measurement. One important aspect of using that conclusion is that the knowledge of physical characteristics of the radiated structures must be combined with the data analysis. In further investigations it is necessary to explain, how the vectorial character of acoustic field influence the value of acoustic power which is "measured" by pressure microphones.

Intensity vector distributions presented graphically in this paper shows the powerful analysis capabilities of acoustic intensity measurements. Some examples have been given of interesting patterns of energy flow in the vicinity of the radiated structures, which could not be obtained from the more commonly used and measured data concerning pressure only however pressure measurements are relatively easy to make.

Intensity measurements provide additional data which may be of great value, although further research must explain the differences between the results obtained by means of the conventional and intensity methods of measurement; now it is impossible to claim that the sound intensity technique may totally replace the classical methods.

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