SOUND INTENSITY DISTRIBUTION AS AN UNDERWATER ACOUSTIC INVESTIGATION PROCESS

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The subject matter of this research is underwater noise generated by sailing vessels in shallow seas. The classical method for measurement of underwater noise involves measuring effective acoustic pressure and fits for purposes in the free far field of the source. Despite its popularity, the method does have some significant limitations. Investigations of underwater noise generated by moving vessels in shallow seas are almost solely confined to the near field. In addition, this has a high level of interference and numerous wave reflections. This is why, as well as using the acoustic pressure measurement method, a complementary method for measuring acoustic wave intensity is used increasingly often.

The measurements were taken using an underwater measurement module equipped with a set of detectors. Submerged at 20m, the object moved along a designated trajectory at a preset speed (as determined by the parameters of the ship's machinery). Because all of the on-board equipment generates ship-specific noise, additional measurements were taken of the vibrations generated by selected ship's machines to identify those sources.

If known, the distribution of the acoustic field from vessels helps to identify the characteristic frequencies generated by the ship's equipment and machinery.

The paper includes a comparison of acoustic wave intensity and acoustic pressure measurements taken under the same ambient conditions and over the same period.

INTRODUCTION

This publication presents the results of the experimental research of the underwater effects of propagation of elastic waves caused by a hull vibrations generated by ship. There are a number of methods for measuring vessel-generated underwater noise. This kind of noise can be divided into continuous spectrum noise generated by:

- the cavitation of the propeller,

- machine turbulences,
- hydrodynamic and hull flow noise

and discrete spectrum noise generated by :

- the main engine room:
    - main engines.
    - turbines,
    - transmission gears,
    - shafts
- propeller rotations
- auxiliary engine room:
    - power generators,
    - compressors,
    - electric motors,
    - pumps,
    - fans.

Vibrations generated by a ship's mechanisms are transferred by the shell plating to the marine environment and propagated as acoustic waves. These can be measured with passive hydroacoustic systems using underwater sensors, i.e. hydrophones. The relations between underwater noise level and a ship's vibrations are presented.

1. MONITORING OF VIBRATIONS AND NOISE USING ACCELEROMETERS

To complement the examination of underwater acoustic field distribution, accelerometers were used and installed in selected places inside the ship, consistent with the main sources of the vibrations on the ship. Fig. 1 shows the position of the accelerometers.

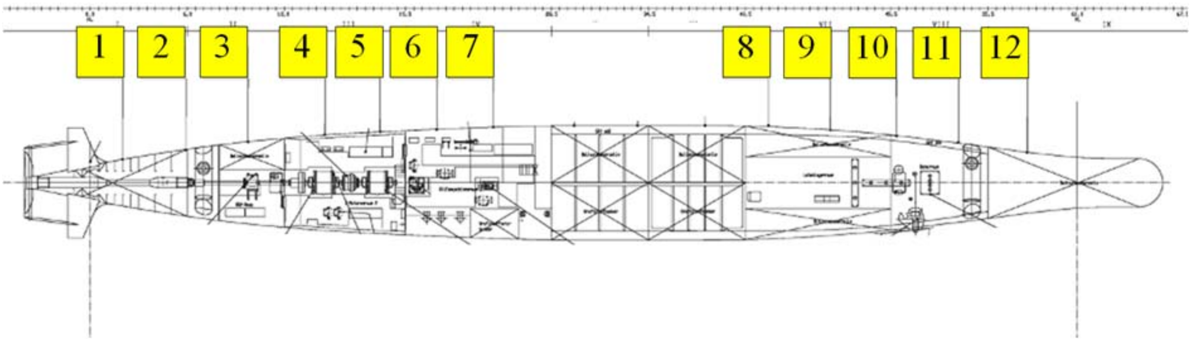

Fig. 1. Location of accelerometers taken into account during measurements.

Accelerometer output signals were recorded and then analyzed for the occurrence of characteristic features in their spectra. This is a widely used analytical method for signal comparisons in a selected band, which depends on the parameters of the recording system. Fig. 2 shows the spectra of signals recorded from 12 accelerometers within the frequency band ranging from DC to 1 kHz.

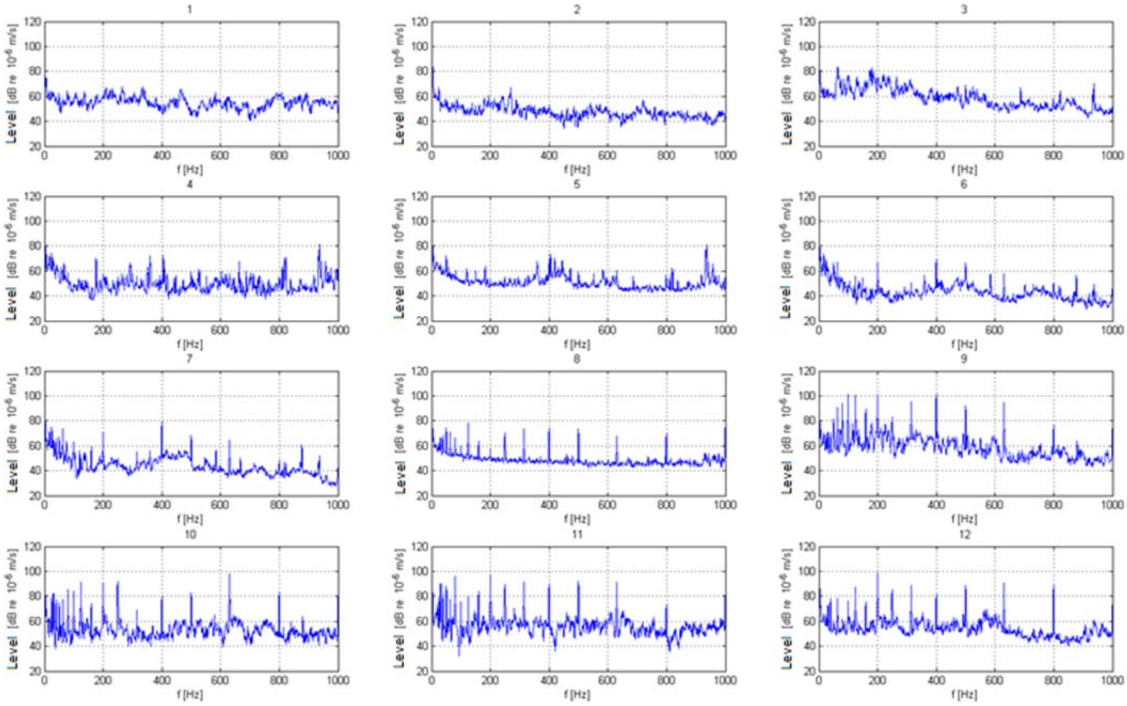

Fig. 2. Signals spectra from 12 accelerometers in band from DC to 1 kHz.

In the selected frequency band comparison was made between accelerometer signals and related signals reveived from the hydrophones in the underwater measurement module. Fig. 3 shows an example of a signal band 200 Hz for a 500 Hz central frequency component. In the selected band we can also see a component frequency 400 Hz.

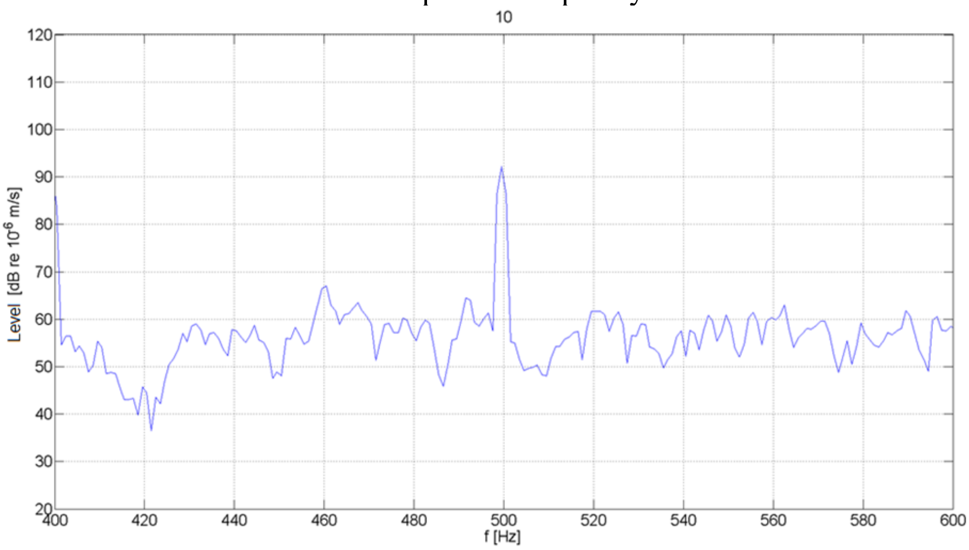

Fig. 3. Hydrophone signal spectrum in 200 Hz band.

When signals are analyzed for their characteristic frequency components, we can also apply the sound intensity method to complement the acoustic pressure method measurement in the area affected by noise.

2. DISTRIBUTION OF SOUND INTENSITY RECEIVED FROM VESSELS

Underwater measurements of physical field disturbance caused by moving ships were carried out using a passive monitoring module deployed on the sea bottom at a specific depth. Thanks to its design, the platform could be used to study the parameters of the hydroacoustic, seismic, electric, magnetic and hydrodynamic fields. Given the objective of the study, the focus was on disturbances in the hydroacoustic field. The measurement set consisted of four hydrophones of very similar parameters placed at the vertexes of a regular tetrahedron. Thanks to this configuration, we could follow the trajectory of the sound source in space. The algorithm applied in this investigation uses the relation for the components Ix, Iy and Iz of sound intensity which is expressed as follows:

$$I_x = -\frac{\mathrm{Im}\{G_{W_{x1}W_{x2}}\}}{2\rho\omega x}, \tag{1}$$

Where:

ρ – water density,

$\omega = 2\pi f$ – angular frequency of the analyzed signal (f – frequency),

$2x$ – distance between hydrophones,

$\mathrm{Im}\{G_{W_{x1}W_{x2}}\}$ – imaginary part of the noise signal cross spectrum.

$G_{W_{x1}W_{x2}}$ - cross spectrum fo signals

The relations for components y and z of the intensity are determined just as in the previous formula.

With the component data of sound intensity known, the bearing is defined using the relations:

$$\varphi = arctan\left(\frac{I_Y}{I_X}\right), \tag{2}$$

$$\theta = \arccos\left(\frac{I_Z}{I}\right), \tag{3}$$

Where: $I = \sqrt{I_X^2 + I_Y^2 + I_Z^2}$, and φ and θ are the angles of azimuth and elevation.

Subsequent calculations were made based on the frequency analysis of signals from the accelerometers and the relations described above. These results changes of the values of intensity components in the function of distance to source. The results are shown in Fig. 4.

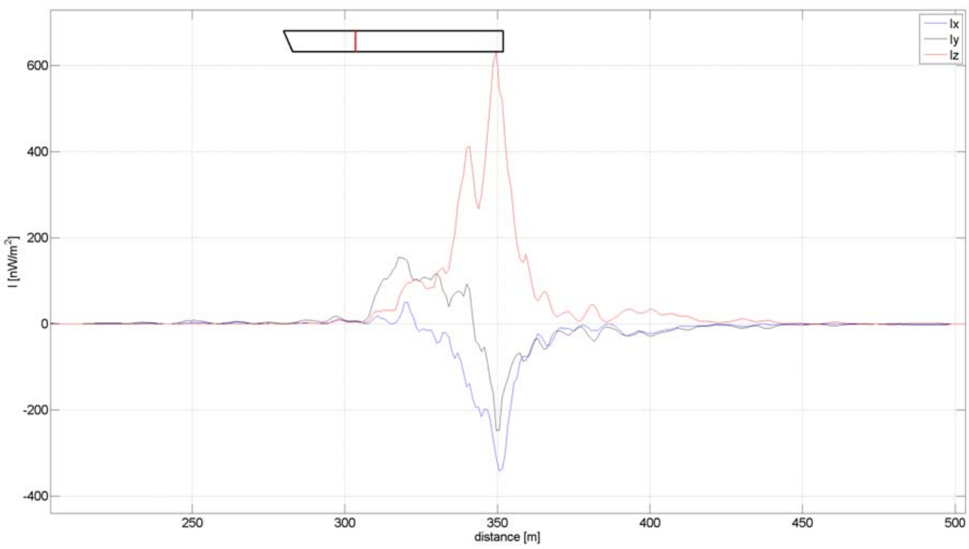

Fig. 4. Sound intensity components obtained from moving vessel.

The spherical propagation of sound wave was assumed and the result is the distribution of sound pressure within the area in which the object, i.e. the ship, moves. The distribution is shown in Fig. 5.

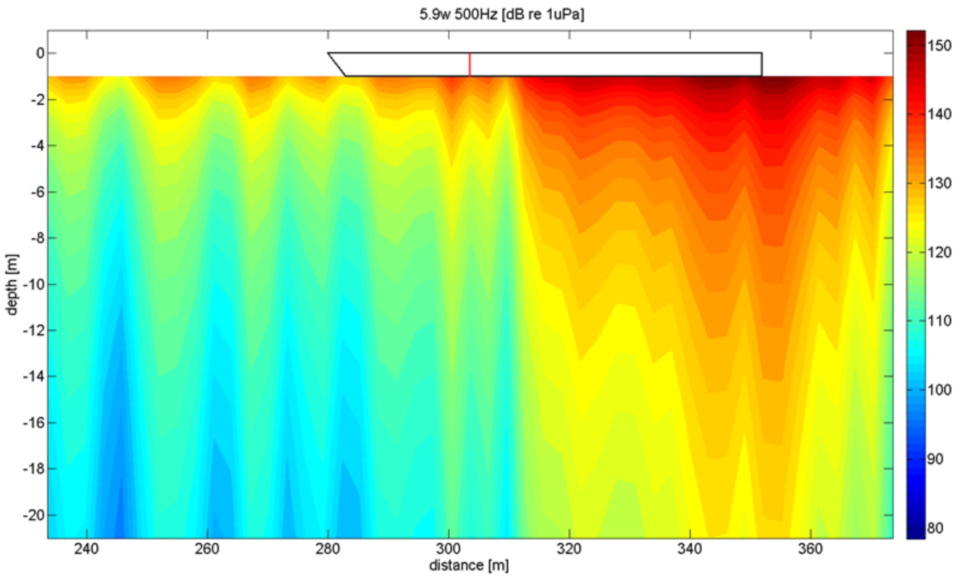

Fig. 5. Sound pressure distribution based on noise propagation.

Once known, the values of sound intensity components could be used to determine the resultant intensity of the acoustic wave in the function of time. When presenting the speed of the object, the changes in intensity were given in the function of distance. By analogy to the previous figure, the sound intensity distribution within the ship's movement area was obtained. The distribution is shown in Fig. 6.

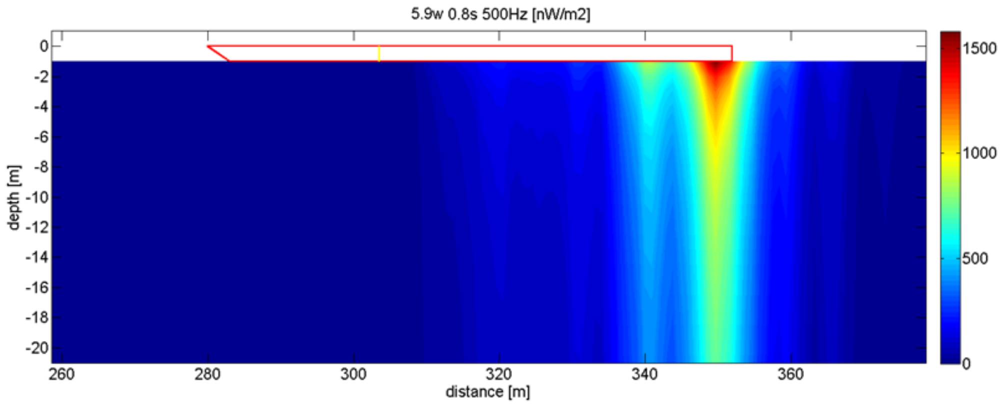

Fig. 6. Sound intensity distribution for the same moving vessel.

The distributions are for a component with a frequency of 500 Hz of the signal being measured. Other components generated by the operation of the ship's mechanisms may have different features. This is made plausible by the fact that a ship is not seen as a single source of noise. Instead it is considered as a set of sources that can be found in different parts of the ship. The design itself, with the frame and shell plating, also has an effect on how vibrations and sound are propagated from source to water. To exemplify this, the distributions of intensity for 405 Hz and 633 Hz components are presented (Fig.7).

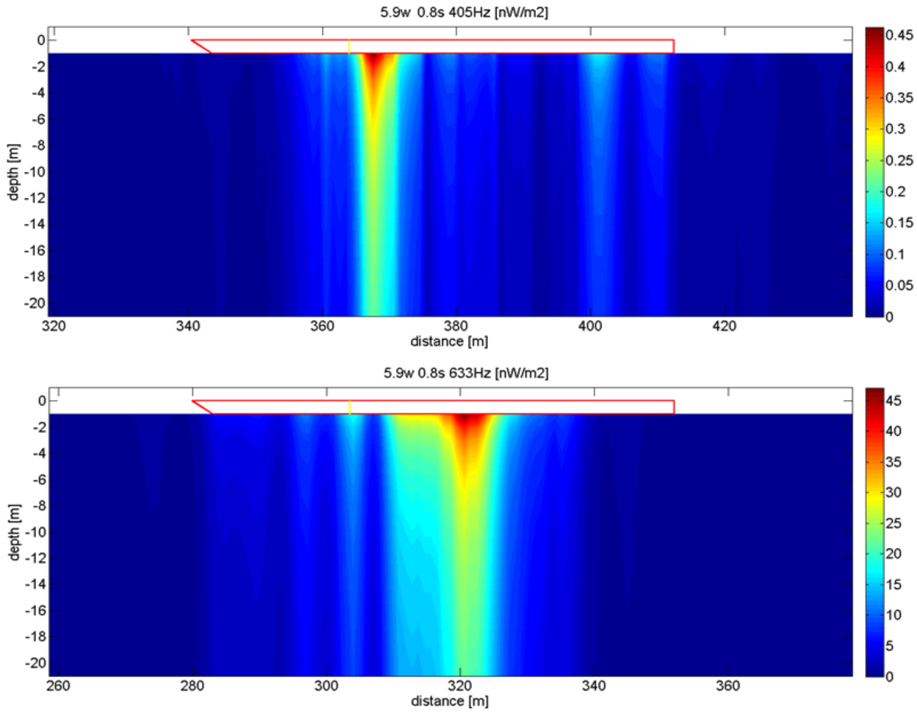

Fig. 7. Difference between sound intensity distribution of the same source but with different frequency components.

3. CONCLUSION

Unlike acoustic pressure, sound intensity provides more clarity about the source acoustic field, in particular in the near field, where acoustic pressure has a number of maxima and minima and strong wave interferences. A key advantage of using sound intensity measurement is its directivity because intensity is characterized not only with the surface density of the acoustic power stream but also by its direction and sense.

Measuring the intensity of a ship's underwater noise provides the basis for developing:

- methods for remote detection of a ship's machinery's technical condition
- methods for minimizing ship-generated noise.

Knowledge of a ship's acoustic field can be applied in areas related to the positioning, identification and monitoring of vessels.

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