SHIP'S UNDERWATER NOISE MEASUREMENTS USING SOUND INTENSITY METHOD

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Ship noise is a most important part of the field of underwater acoustics. Its reduction and monitoring is an important aspect in the performance of underwater acoustic systems and in the habitability of the vessel for the crew and passengers. In naval operations the noise radiated by a ship is also dominant source of information for underwater sonar systems. Sound intensity is the vector quantity which informs us about the sound power flux, the position and the direction of the sound source. The probe tracks the position of source and at the same time, measures the component of sound-intensity vector. Generally only one component of vector sound intensity was measured, perpendicular to a given measurement surface. The sound intensity of a moving source includes effects such as flow noise that are not present when the source is stationary. The accuracy of measuring acoustic intensity using two closely spaced hydrophones by correcting the phase mismatch error by measuring the transfer function between the two detector systems was examined. The two measuring hydrophone instrumentation systems were earlier calibrated. Our results have been obtained using digital methods, where was used PULSE measuring system.

INTORDUCTION

Very little data is available on sound intensity and even sound pressure level (SPL) measurements and noise spectra of small boats or big vessels. Noise from warships and merchant vessels with keel aspect source levels ranging between 140 and 192 dB re 1 μPa at 1 m. Hostile naval forces also use the underwater noise signatures radiated by surface ships and submarines for detection and classification of ships as targets. At low speeds up to 8 kn, the underwater noise signature of the ship is dominated almost totally by tones from the ship's Diesel generator set. Above this speed, the ship's signature is dominated by three sources: main engine diesel firing rate harmonics, blade harmonics, and wideband cavitation noise. The effect of the noise aspect of maritime modern civilization on sea ecosystems is

frequently ignored, but it is beginning to be recognized as a trouble worthy of further research.

A small number of measurements have been made of the full sound intensity vector, and little has been done so far to explore its use. The sound intensity hydrophone probe was designed to measure sound intensity together with the unit direction of flow as a vector quantity. This was achieved by setting up two hydrophone probe to measure the sound energy flow. The distance between them was 120 mm, it allows to determine the sound intensity with accuracy + / -1dB in the frequency range 150 Hz – 2 kHz. A conventional hydrophone can measure sound pressure, that represents sound intensity at a specific place. The main advantages of vector sound measurements are:

- determining which parts of the complex source radiate most noise,
- finding the directions of sound sources,
- possibility of measurement in the near field.

The underwater acoustic intensity probe is constructed and tested to measure the pressure and acoustic particle velocity by two hydrophones at closely spaced locations.

1. METHODS OF MEASUREMENT

Usually an array of pressure transducers is used to determine the direction of a sound source in water. But in this paper we show the ability of a vector sound intensity probe to determine the direction of a sound source.

Before the measurements were carried out in the sea, the calibration experiment had been performed. The measurement of the harmonic wave intensity had been carried out in the anechoic water tank for different distances Δr between hydrophones as a function of frequency. The measurements were made in a water tank of dimensions 1.2 x1.2 x 1.2m. The schematic drawing of the measurement system was shown in the earlier paper "Tracking the Underwater Noise Source Using a Vector Sound-Intensity Probe" [1].

The noise radiated by ship is always measured by running this ship past a stationary distant measurement hydrophone in order to determine the acoustic pressure or using a probe to determine the sound intensity. Various types hydrophones, hydrophone arrays and hydrophone probes have been employed for this purpose.

The simplest arrangement uses to measure the sound-intensity component consists of two pressure detectors. The signals received by hydrophones were amplified by means of two identical Brüel & Kjær 2636 amplifiers.

The analyzer can compute the sound intensity on-line and the procedure used for this computation is based on FFT algorithm.

More complex configuration involve three or four hydrophones. In our measurement two detectors were fixed 1 m above the sea bottom and strung in a line perpendicular to a running vessel. The measurements have been made in the Baltic Sea shallow water. In our cases the vessel under test have been arranged to run at a constant speed and constant course in order to pass the measurement hydrophone probe at a known distance. During the run broad-band analogue tape and digital recordings have been made and late subjected to determine the ship's position and also analysis in different frequency bands. The ubiquitous spherical-spreading law is normally applied for these measurements. Several investigations have indicated that spherical or inverse-square spreading is a good approximation for expressing the variation of ship noise with range at close distances, even for low frequencies in shallow water.

2. RESULTS OF MEASUREMENTS

In this article there are mainly results of increasing the range because of changing the method of measurement from the pressure into the sound intensity. In this situation we applied the measuring method which used a simply probe that consists of two identical sound pressure detectors – hydrophones. Theoretical estimations of the sound energy level close to the source are not effective.
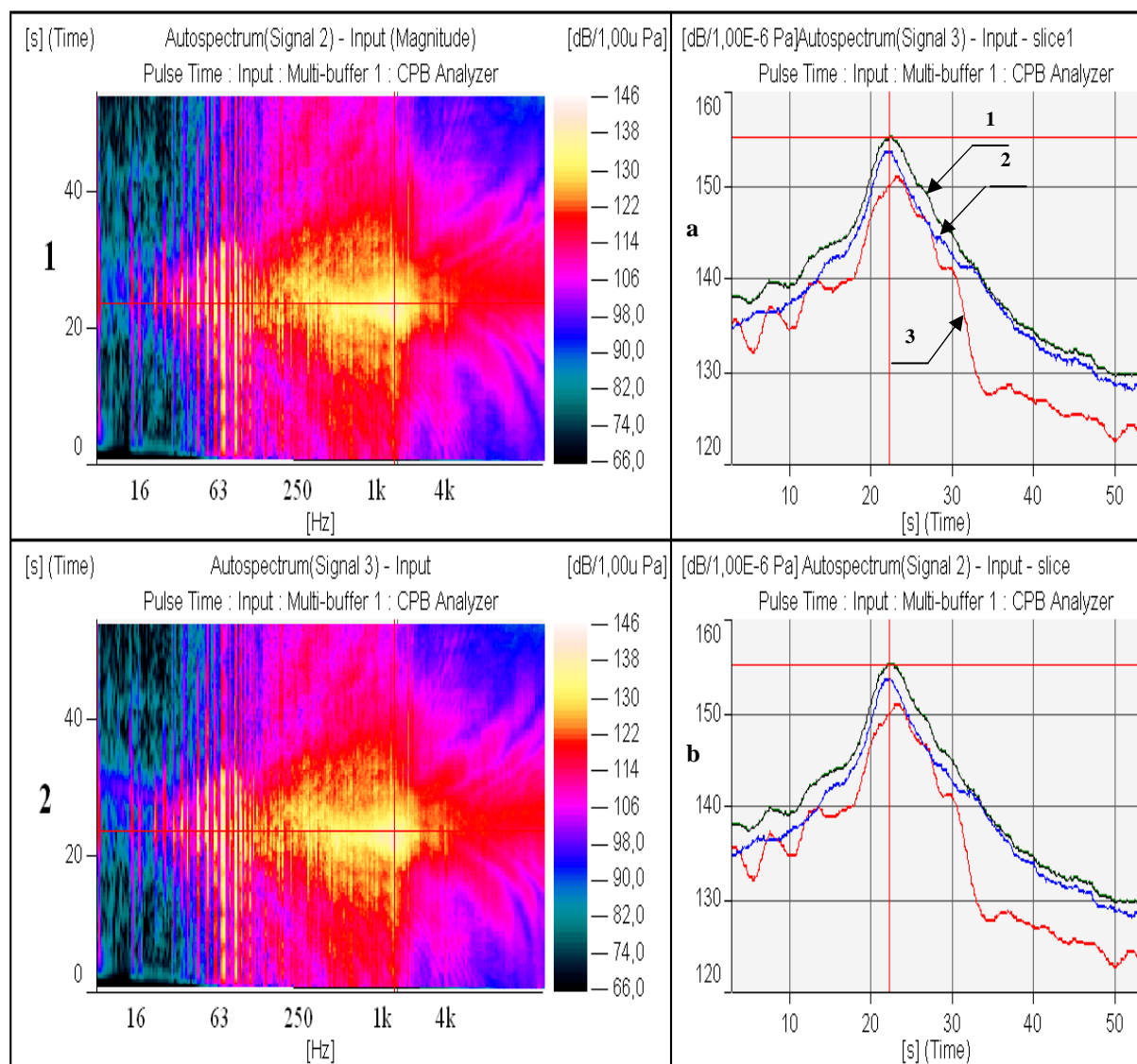

Fig.1. Results of the underwater acoustic measurements with used the sound intensity probe. The speed of a ship was 6,6 kn. where:
1, 2.   Spectrograms of the sound field where range is from 6,9 [Hz] to 11,22 [kHz] ,
a, b.   Sound pressure level as function of time for:
1. ——— Sound pressure level L = 155 [dB] in the range from 6,9 [Hz] to 11,22 [kHz],
2. ——— Sound pressure level L = 154 [dB] in the range from 100 [Hz] to 11,22 [kHz],
3. ——— Sound pressure level L = 151 [dB] in the range from 6,9 [Hz] to 100 [Hz].

The noise level depends mainly on resistance putting up by the sea water to the moving object, what usually is connected with forward speed or rapid change of acceleration in case of maneuver movements. In the shallow sea when we usually carried out the measurements of underwater noise produced by moving objects the characteristics obtained by means the acoustical pressure only is not correct due to the near field phenomena. For determination of the sound intensity vector we need to know both values the sound pressure and the acoustic velocity of vibrating particles of medium. Because of the

complexity of measuring procedure of the sound intensity usually As is know the sound intensity is a product of sound pressure and particle velocity. During direct measurement we obtain the sound pressure history and we need also to know the second function of mention above product. It can be determined by mean of well known Euler equitation.The both spectrograms shown on figure 1 equal results from different hydrophones and character of underwater noise confirmed that is possible to measure in our case using a vector sound intensity probe. The pointed place where spectrograms were taken - the sound pressure level *SPL – 138 dB,* frequency *f - 930,6 Hz* and time *t – 23,1 s*
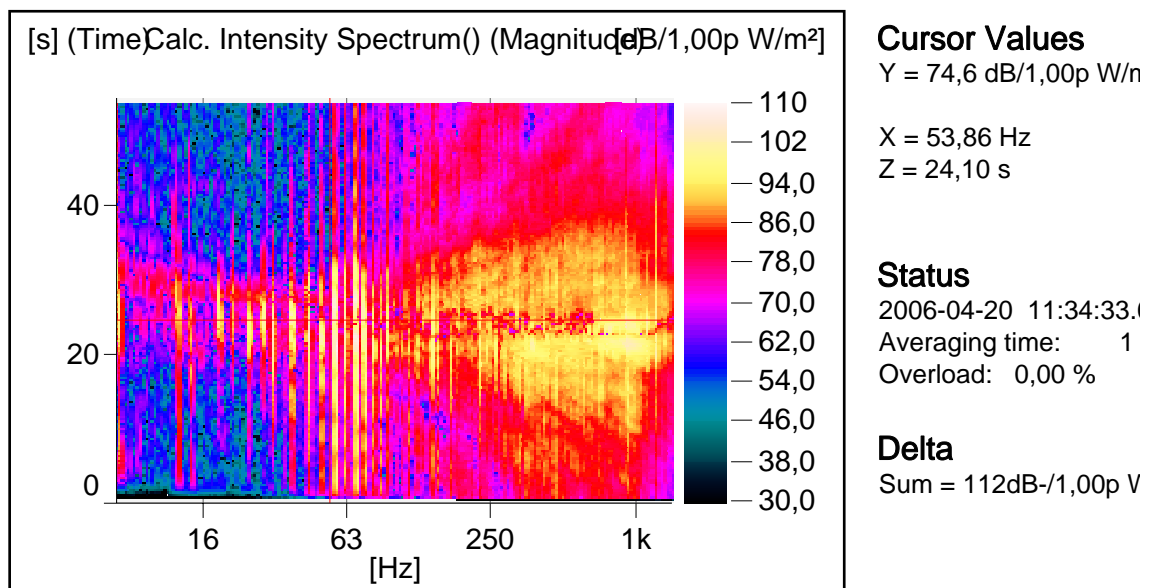

Fig.2. Typical spectrogram of the ship's sound intensity

Signal from acoustics transducers are transmitted to the registering and analyzing laboratory. On the basis of these measurements, a set of characteristics that determine individual features of examined sources is obtained. The spectrogram of sound intensity characteristic for a surface of the ship is shown in figure 2.
The characteristic of the sound intensity as a function of distance between source and receiving array is shown in the Figure 3.
Pointed places where the sound intensity levels have its minimum to mark the changes of directions of power into the sound intensity probe. This change of direction can be shown by analyzed the real part of complex spectrum Figure 4 shows this spectrum analyze.

Cursor Values
Y = 91,3 dB/1,00E-12 W/m
X = 53,44 Hz
Z = 24,10 s

Status
2006-04-20 11:34:33.073
Averaging time: 1 s
Overload: 0,00 %

Slice Definition
Freq. Band Slice 1 (Sum)
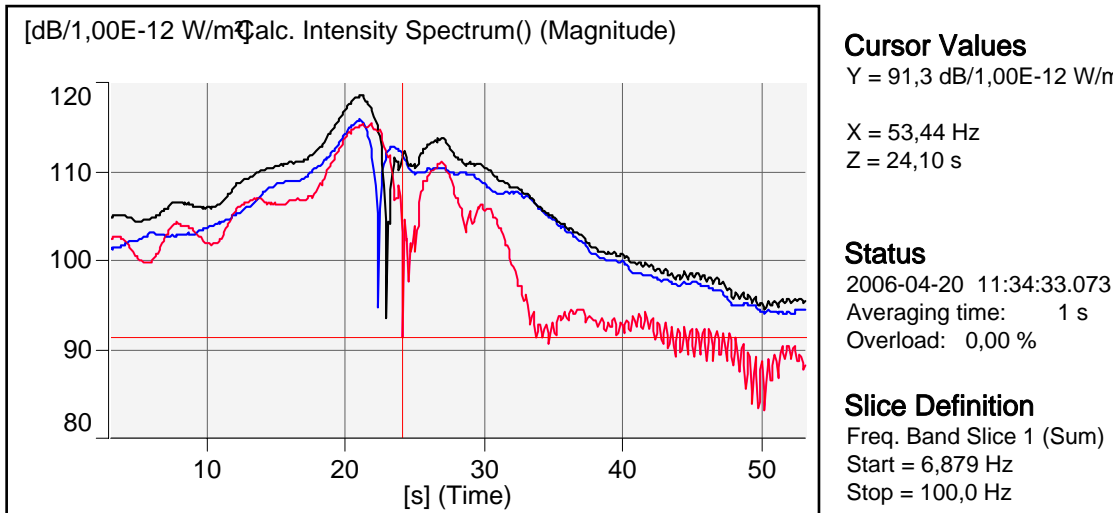Start = 6,879 Hz
Stop = 100,0 Hz

Fig.3. The sound intensity levels in the function of time when a ship was going above the vector probe. Keel-aspect levels for different frequency ranges:

1. ——— Minimal level of the sound intensity L = 93,4 [dB], for the time t = 22,90 [s] frequency range from 6,9 [Hz] to 1,334 [kHz],
2. ——— Minimal level of the sound intensity L = 94,7 [dB], for the time t = 22,30 [s], frequency range from 100 [Hz] to 1,334 [kHz],
3. ——— Minimal level of the sound intensity L = 91,3 [dB], for the time t = 24,10 [s], frequency range from 6,9 [Hz] to 100 [Hz].

Cursor Values	Cursor Values
Y = 118 dB/1,00E-12 W	Y = 114 dB-/1,00E-12 V
X = 670,200 Hz	X = 670,200 Hz
Z = 21,10 s	Z = 26,80 s

Status	**Status**
2006-04-20 11:34:30.0	2006-04-20 11:34:35.7
Averaging time: 1 s	Averaging time: 1 s
Overload: 0,00 %	Overload: 0,00 %

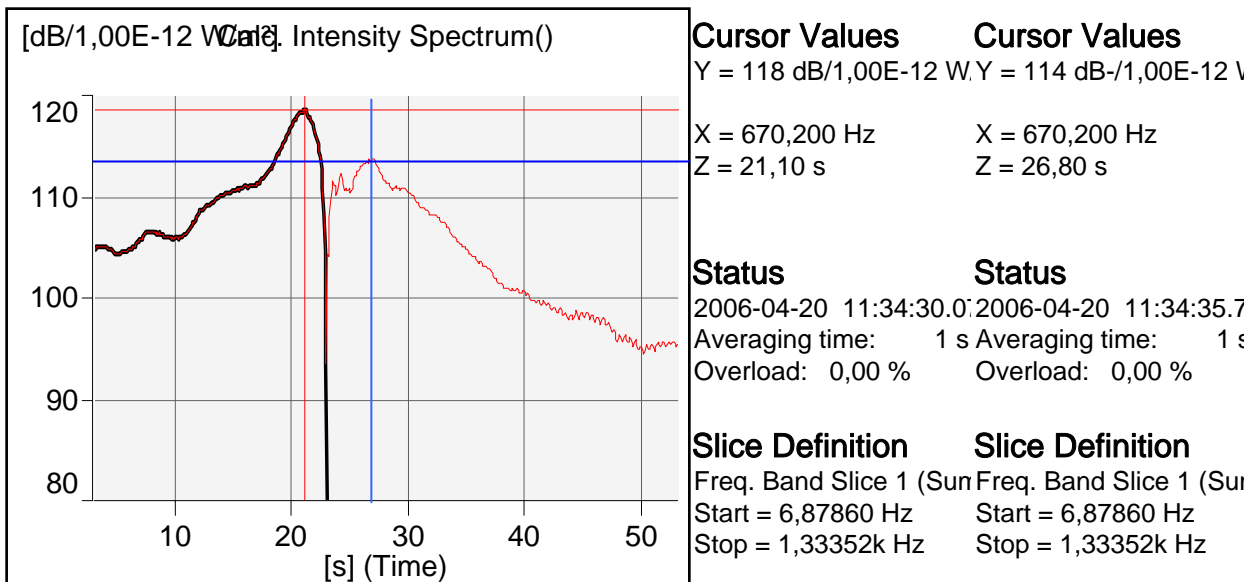| **Slice Definition**	**Slice Definition**
Freq. Band Slice 1 (Sun	Freq. Band Slice 1 (Sun
Start = 6,87860 Hz	Start = 6,87860 Hz
Stop = 1,33352k Hz	Stop = 1,33352k Hz

Fig.4. Computed real part of the complex sound intensity level made for the frequency from 6,9 [Hz] to 1,33 [kHz]

The positive level of the sound intensity can be observed from the time equals *22,9 s* of the running ship. Red line shows this moment.

Maximum sound intensity levels are marked, here we are *L = +118 dB re 10-12 W/m2* observed at *t = 21,1 s*. Minimal sound intensity levels are for *L = -114 dB* in the time *t = 26,8 s*.
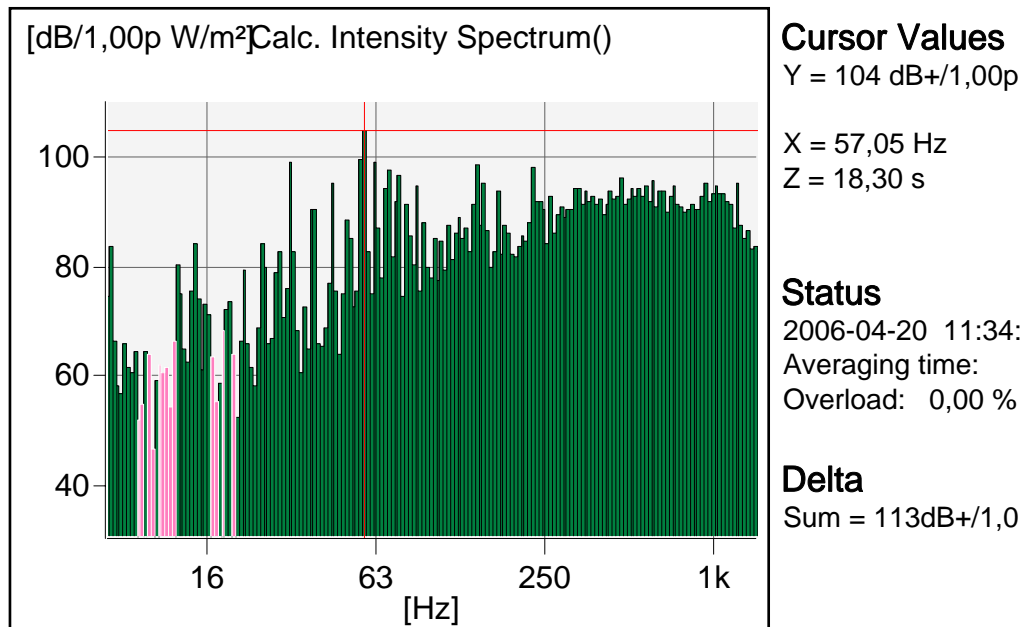

Fig.5. Spectrum of the sound intensity level in function of frequency. The ship was running in a straight line into the probe
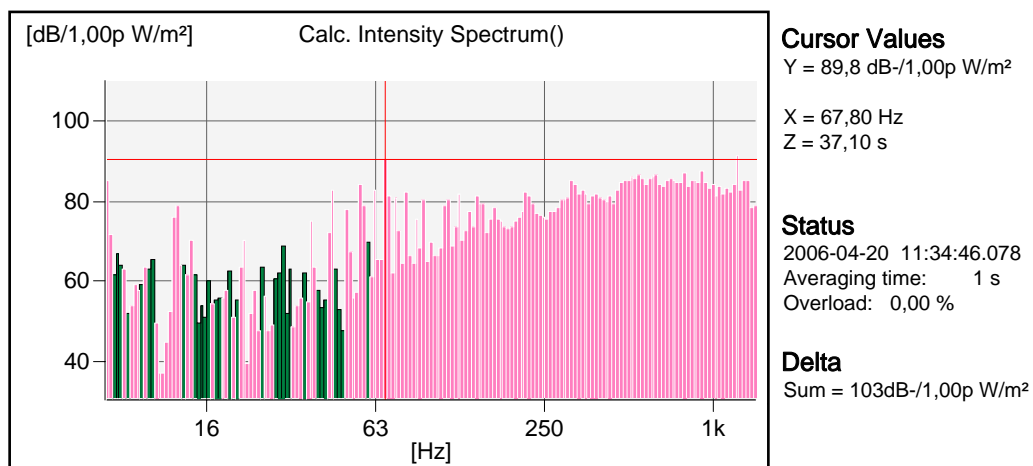

Fig.6 Spectrum of the sound intensity level in function of frequency. The ship was running in a straight line after the probe

More accurate bearing from the sound intensity probe which used only two hydrophones you can get monitoring simultaneously symbols plus or minus and phase of the acoustic signals. Therefore the signals from noise generated by a ship were changed in this case that show the spectrogram of phase in the whole band of frequency.

The tonal noise containing discrete frequency are related to machinery, gears, and modulation of broadband noise. Ship noise is also characterized by transient noise caused by impacts, loose equipment, or unsteady flow.
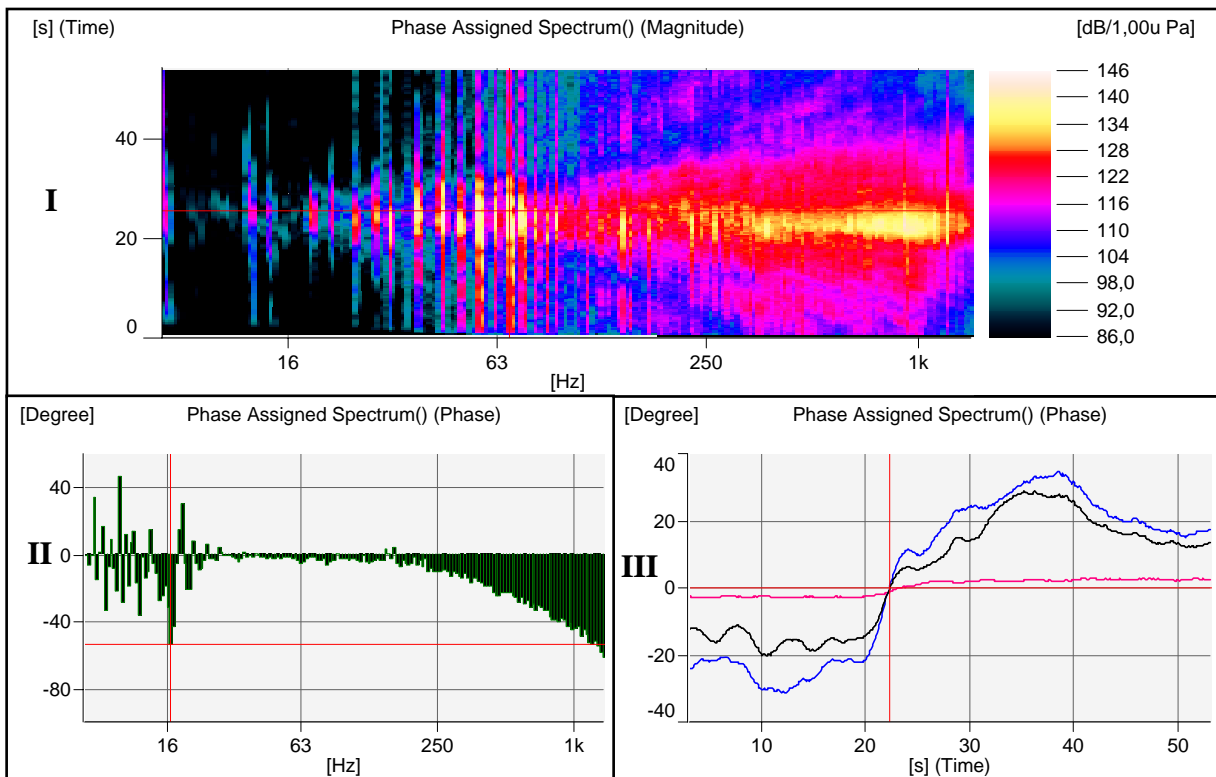
Fig.7. Underwater ship noise I - Spectrogram of the underwater ship noise, II - Phase of the underwater ship noise, III - Phase of the underwater ship noise for the different frequency ranges:

where: 1. ▬▬▬ from 6,9 [Hz] to 1,334 [kHz],
2. ▬▬▬ from 100 [Hz] to 1,334 [kHz],
3. ▬▬▬ from 6,9 [Hz] to 100 [Hz].

Figure 8 shows a spectrogram of the radiated noise in which auxiliary machinery tonal noise governs the continuous spectrum.
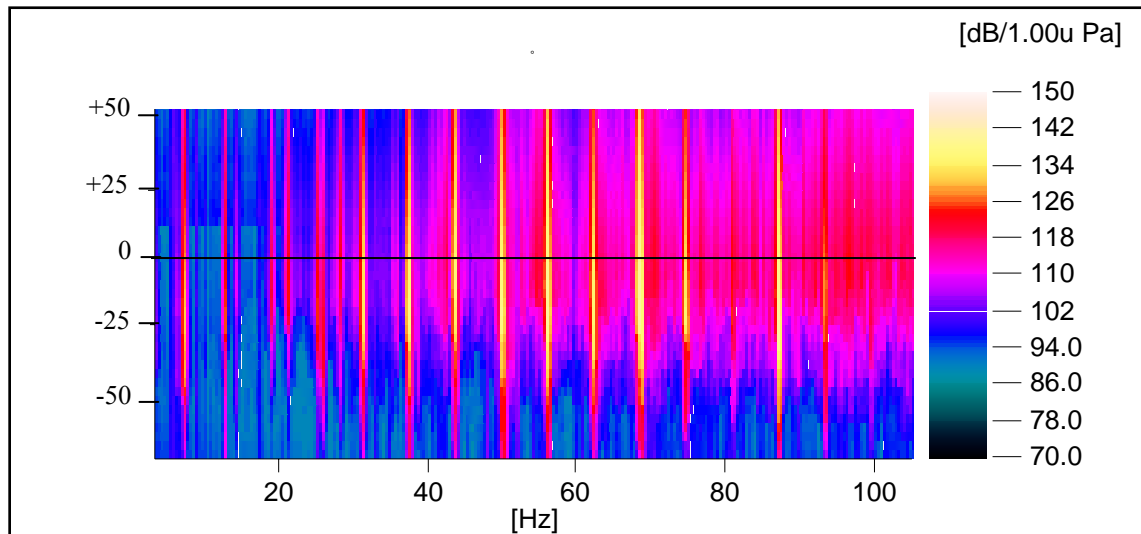
Fig.8. Spectrogram of the noise made by a ship going with the speed of 4 kn when the range of frequency is up to 100[Hz]

4. CONCLUSIONS

Applying the sound intensity measuring method we can carry out the measurements in near field of a source of acoustic waves. It can be important in the case when we want to measure the ship's noise in the shallow sea. Otherwise on the base of intensity characteristics one can determine the direction of movement, determination of the direction of a source moving along a straight line. Analysis of tracing the course of a moving object in real environment using the probe consisting of two hydrophones technique imposes limitations on the useful frequency range of the measuring system. A basic systematic error is inherent in the approximation of the pressure gradient by a finite pressure difference. This error is most severe at high frequencies. The approximation error can be calculated for ideal sound fields and ideal sound sources. Since the sound field is rarely known in sufficient detail, such calculations only give an idea of the useful frequency range.

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