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Transmission of low frequency sounds from ships into water environment

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The main goal is presentation the broad experimental research associated with the transmission of acoustic energy generated by moving objects into the water. The paper present the methodology of evaluations of the transmission of low frequency vibration from the mechanisms of ship into the water environment. For that purpose the research of vibration distribution over ship's hull were conducted along with the hydroacoustic field.
The underwater sound measurements were performed both for sailing condition and during anchorage.
The hull is source of complex surface shape inducing waves of different frequencies depending on the working parameters of ship's machinery. As a result of mechanical incitement of the hull's surface a complex distribution of vibration is created depending on vibration spectra of the primary sources as for the main propulsion units, generators or other mechanisms.
This research allowed to determine the transmission coefficient for the mechanical vibration energy going through the ship's hull and the evaluation of influence on the hydroacoustic field of a ship. The values signaling the changes of the technical condition of machinery and propulsion system.

1 Introduction

Hydroacoustics Department of the Polish Naval Academy more than thirty years leads investigation common with sea-based target detection systems, target identification (target patterns stored in data bases) and passive ship defence using wide spectrum acoustics method and skills.

One of the most important area is experimental research associated with the transmission of the low frequency acoustic energy generated by moving objects into the sea water. The research are provided for the following aims:

- Scientific research/investigations,
- Passive ship defense,
- Monitoring self underwater noise,
- Protecting of water environment (sea mammals),
- Classification and identification objects,
- Reconnaissance of sea object,
- Description of the technical state of ship,
- Improve acoustics research method and skills,
- Development of passive hydroacoustics systems.

These results are very important for save people and warships during duty at the sea. This paper presents chosen the main methods and results of acoustics investigations lead in the Polish Navy.

2 The main method of investigations

The kind of method depend on sort of interesting area of results.

The basic method is the investigations of ship on the mooring trial, when the ship is anchoring on the chosen depth of sea as shown in Fig.1.

The method consist of parallel measurements vibration of mechanism which are main sources of underwater noise and underwater noise.

The vibration and underwater soughs measurement system there are on the board of the ship. The demonstration location of measurement probes are presented in Fig.2.

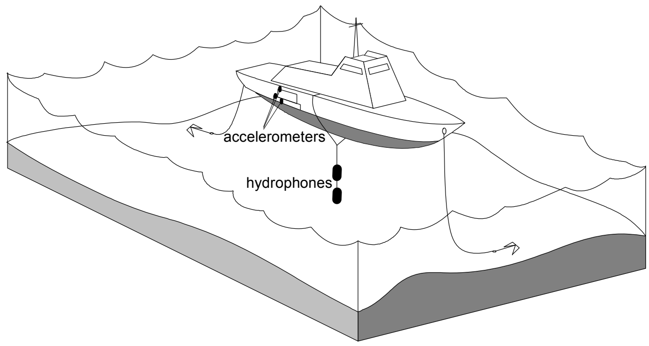

Fig.1 The mooring trial – one of the method of the investigations sources of underwater noise.

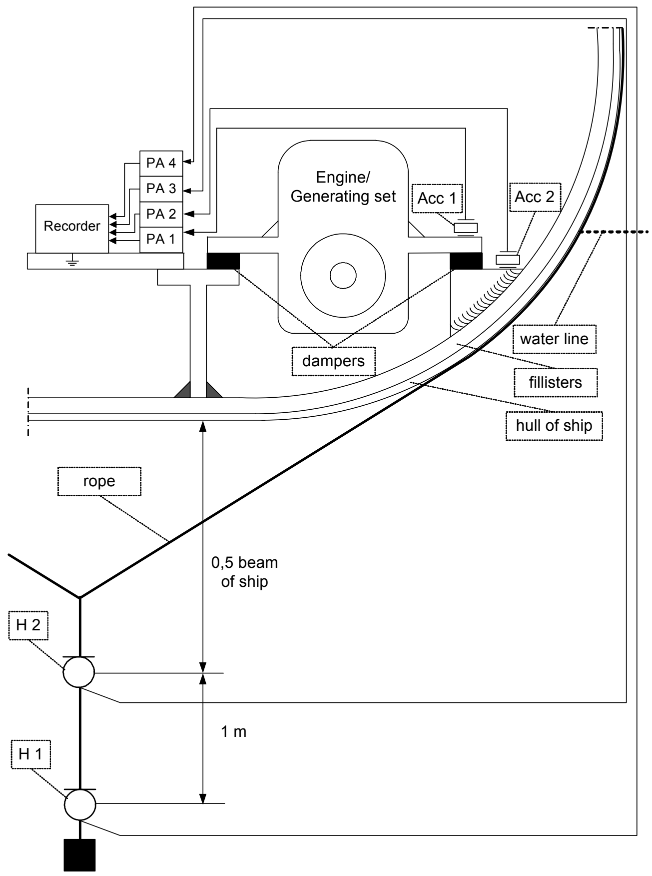

Fig. 2 The method of measurement ships generating set: H1,H2 – hydrophones, PA1-PA4 – measurement preamplifiers, Acc1, Acc2 – accelerometers.

The measurement system there are on the board of the ship. The research scheme of this method showed in Fig.3.

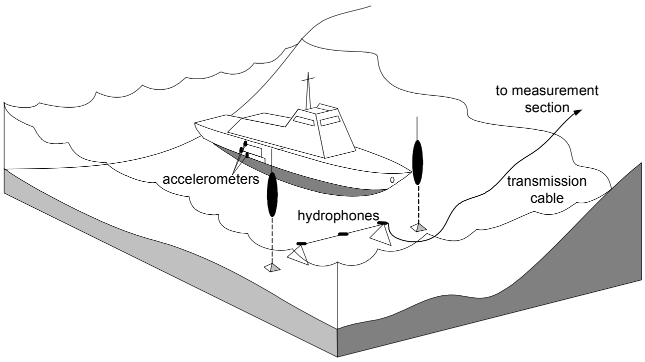

Fig.3 The dynamic measurement of ship's noise – one of the method of the investigations sources and spatial distribution of underwater noise.

The next method of investigations is dynamic method of measurement underwater noises. The sensors there are directly on the permanent special construction situated on the bottom of sea. The directional buoys lead ship strength above underwater section of hydrophones. This method allows calculate longitudinal and transverse distribute of underwater sound generated by hull of moving ship.

The measurement method using special measuring ship puts into use when it is necessary measure distribution of ship's noise on the different depth. Usually between 10 and 100 m depths shown in Fig.4.

In last methods two groups of researchers take part in investigations. First group on the acoustics range measure underwater noises and second group on the board of investigated ship measure vibration the main sources of sound.

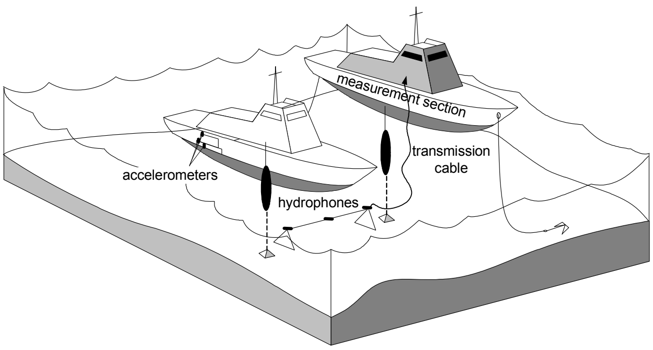

Fig.4 The dynamic measurement of ship's noise – one of the method of the investigations sources and spatial distribution of underwater noise.

3 The ships' sources of underwater noise

The Southern coast of The Baltic Sea is characterized by a sandy, stony coast and shallow water. Bottom contour of depth 20 meters is found with the about 3 Mm from the coast. Therefore the most examinations are being carried out on depths from 10 to 50 meters. In shallow waters, almost everyone sound emitted by the hull of the ship is penetrating seas to the bottom, so it is very important to understand the radiated underwater acoustic distribution of surface ships, submarines and other object. The mines lie at the bottom the sea (e.g. mines) making a threat to ships sail across in the vicinity. An elimination of the risk of ships is one of aims of examinations through the minimization of acoustics' signatures of ship.

The second aim to provide the investigation is to determine the transmission coefficient for the mechanical vibration energy going through the ship's hull and the evaluation of influence on the hydroacoustic field of a ship. The values signaling the changes of the technical condition of machinery and propulsion system. The main sources of underwater noise is presented in Fig.5.

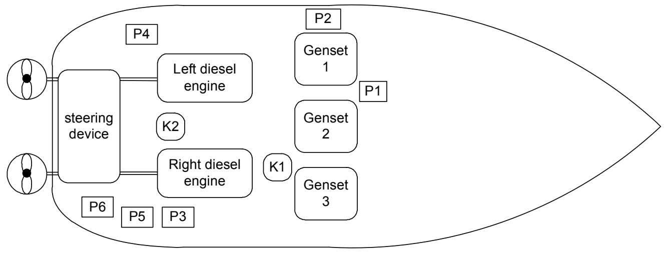

Fig. 5 The example ship with marks the main sources of hydroacoustic field of measured ship. P1- P6 – pumps, K1, K2 – compressors.

The main sources of ship's underwater noise consist of noises generating by:

- The hull of ship,
- The main engines, e.g. gas turbines, diesels,
- The auxiliary system of ship e.g. generating sets, pumps, compressors, steering devices,
- The propellers,
- The energy – electrical system e.g. generators, transformers,
- The pulses in a long pipes, cyclical compression of liquid and gaseous,
- The aerohydrodynamical effect of elements of a hull.

Every ship has an individual character of sources of underwater soughs, it is called acoustics ship passport. An localization and kind of equipment inside of hull of ships change individual character of generating noises.

The evaluations of the transmission of low frequency vibration from the mechanisms of ship into the water environment is especially important because of the widest and the further range.

The analysis of low frequency band allows to determine source characteristic such as:

- Number of shafts and multiple shafts effects,
- Shaft rate,
- Number of propellers blades,
- Frequency of current generated by generating sets,
- RPM of main engines and generating sets,
- Cavitations effects,
- Detection of changes of sources e.g. 1. Shift in frequency caused by change in the propeller revolution rate, 2. Changes of vibration level or underwater noise depend on technical state of ship.

4 The results of examination

4.1 The mooring trial method

This method allows to determine the velocities of vibrations and displacements of the main mechanisms inside the hull. Its were measured for every mechanisms for different coefficients of load (on foundation and hull of ship directly under investigated mechanism). Below, for example, it is presented tests of generating sets. The load increasing of generating sets cause increasing the velocity and displacement of vibrations. The spectra of effective velocities' vibrations were compared with spectra of acoustic pressure level and are presented in Fig. 6 and 7. There were considered the characteristic cases:

1. One generating set is working. The synchronization of generating sets cause that generator 1, 2 and 3 have the same current's frequency. The number of working generating sets is unable to be determined,
2. Two generating sets are working – one without load and not synchronized,
3. Three generating sets are working – two without load and not synchronized (figure 6 and 7).

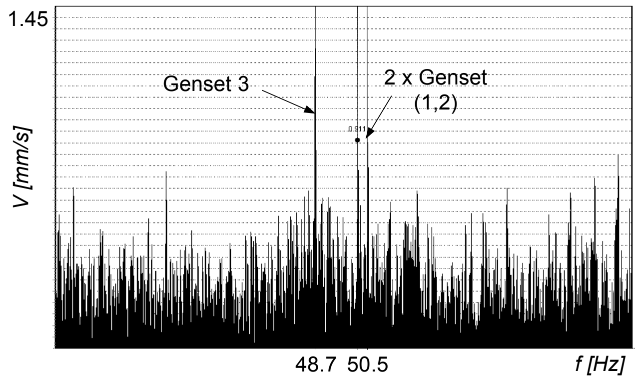

Fig. 6 The velocity spectrum shows voltage frequency for generating set 3. Loading ca. 100 %. Generating sets 2 and 3 worked non-synchronically.

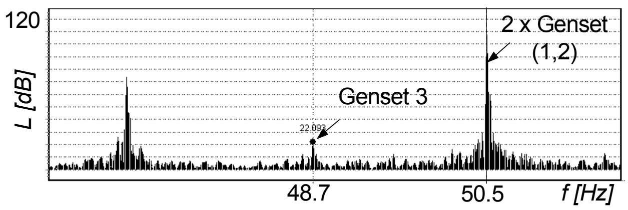

Fig. 7 The level of underwater sound pressure spectrum shows voltage frequency for generating set 3. Loading ca. 100 %. Generating sets 2 and 3 worked non-synchronically.

Similarity of spectral densities of the vibration signals *v(t)* and the underwater noise *p(t)* of these signals are *Gp* and *Gv* and their mutual spectral density.

Coherence function allows to determine the similarity between the spectra of particular signals. In the table 1 a discrete components for which the coherence values are from 0.8 to 1 are shown in Eq.(1) .

$$\gamma_{pv}^2(f) = \frac{\left|G_{pv}(f)\right|^2}{G_p(f)\,G_v(f)} \qquad (1)$$

Relation between mechanical vibration and hydroacoustic field of a ship is presented by transmission coefficient of the mechanical vibration α Eq.(2):

$$\alpha = \frac{L_{1m,1Hz}}{\rho c v} \qquad (2)$$

where:
L 1m,1 Hz – sound pressure level relative to *1μPa,* at *1m* for *1 Hz,*
ρ – density of sea water,
v – velocity of vibration,
c – propagation speed of wave.

f[hz]	coherence	parameters		
		v[mm/s]	p[Pa]	α
48.7	0.8	1.35	$13*10^{-5}$	$1.17*10^{-3}$
50.5	1	0.95	0.1	$5.1*10^{-3}$

Table 1 Parameters of calculate a vibration and underwater pressure.

4.2 The dynamics measurement methods

These methods allow to determine distribution complex sources during movement of ship above the sensor section. The analyze based on the Fast Fourier Transformation, cepstrum, correlations, spectrograms and sound intensity calculations.
Below on the diagram is presented in Fig.8, FFT of primary sources of ship's underwater noise.

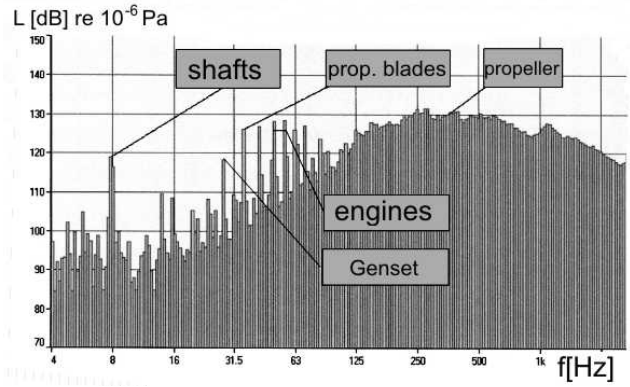

Fig. 8 Acoustics wave pressure spectrum. Primary sources of ship's underwater noise.

Sound pressure levels from different elements of vessels are presented in the Fig.9.
The recognition of these discrete tones allows classification and identification class of ships and technical state of ship's machinery.

The spectrogram presents results of noise measurement of a moving vessel. Lights verticals lines are tones from machinery.

They are from several to one hundred hertz. Above this frequency we have fuzzy spot originates from cavitations and flow.

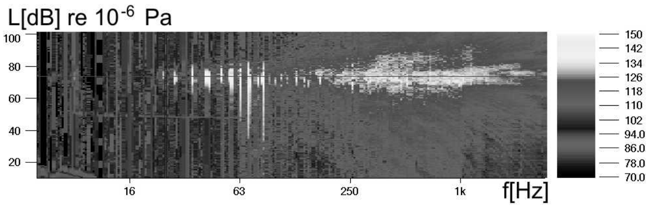

Fig. 9 The spectrogram presents results of noise measurement of a moving vessel.

In the shallow water the best solution to measure sound is the sound intensity. It is often measure instead of sound pressure level which is very changeable here. Sound intensity is measured using special type of probe which consists from two to four sensors. The first picture shows in Fig. 10, a sound intensity spectrogram. The second picture shows in Fig. 11, sound intensity level measured in [W/m^2].

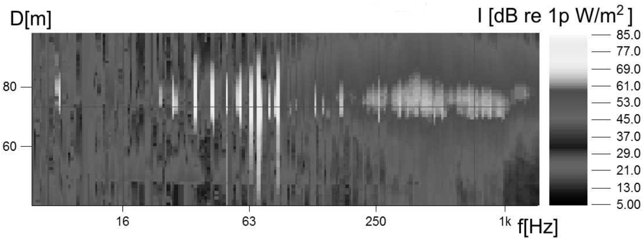

Fig. 10 Spectrogram received when the ship was running with the speed of 8 knots over the array of hydrophones

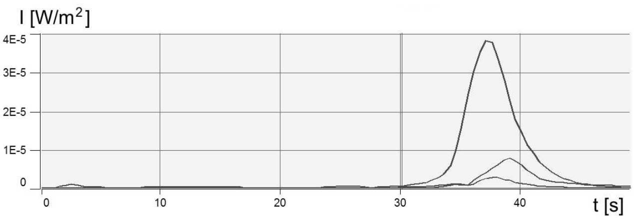

Fig. 11 Sound intensity level. The speed of 8 knots over the array of hydrophones

The sound pressure level is changing with ship speeds.

Firstly the quiet noise is from working auxiliary machinery (generators).

The ship is going here in a quiet mode because main engines and propellers give less noise than auxiliary machinery

After increasing speed of the investigated vessel we have the beginning of cavitations from flow noise and propellers.

The main engines give also some noise in this speed.

Next strong cavitations begins and from now we have the noisy mode.

Further example presents using spectral acoustic analyze to recognition technical state of ship. Firstly. during dynamics measurements it was provided investigations left driving system of tested ship, it shown in Fig. 12. The result was good, so it was acceded to test right driving system, and it was noticed that ca. 1200 Hz is high level of underwater pressure. That is presented in Fig. 12. It was shown that ending one blade of propeller was cut. The lack of part of blade caused bigger level of cavitations and shift frequency to higher frequency and increasing level of pressure.

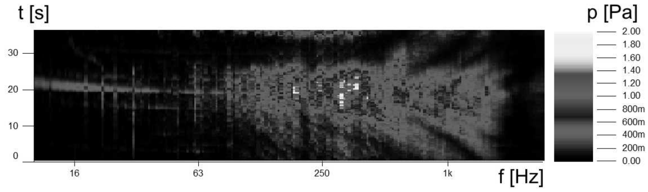

Fig. 12 Spectrogram received when the ship was running only left driving system over the array of hydrophones.

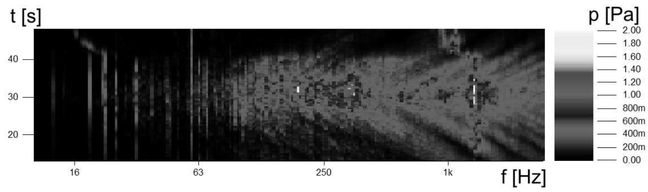

Fig. 13 Spectrogram received when the ship was running only right driving system over the array of hydrophones. Damage right propeller.

5 Conclusion

From this paper we can concluded that:

- Based on the measured underwater noise generated by ship it is possible to get conclusion about sources of underwater noises. In this paper e.g. it is shown that possible is get information about state of load of ship's heavy current engineering system and about readiness for taking part of load by another working, not synchronized generating sets,
- The noise of a moving vessel is connected with the way of mounting and vibration of the machines and next transmission in various paths into the water as underwater sound,
- The knowledge of the levels and structures of underwater noise radiated by ships is important for monitoring self – noise and the technical state of their mechanisms,
- Bad technical state of ship's mechanisms is associated with the increase of the levels of vibration and underwater noise (what you can see in the figures), especially in the spectra (increase of sound level is five or more decibels).

Our measurements show also that we can use data:

- As a guide for approximation, the general run of sound levels measured at sea and their variation with speed, frequency and depth is important for new-built vessels.
- At low speeds, the acoustic signature of a ship is dominated completely by harmonics from the generating set. Above this speed, the ship's levels are dominated by three major sources:
  - main engine diesel firing rate harmonics,
  - blade rate harmonics,

- wideband cavitations noise from the propeller and the hull.

— To have good data, measurements should be made in deep water and mean wave height should be less than 0.5 m with wind speeds less than 5 m/s. The ambient noise level should be low.

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