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UNDERWATER SURFACE SHIP SIGNATURE

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Abstract

In the paper the results of intensive investigations of the underwater–radiated noise by different kinds of surface ships have been presented. To identify the sources of underwater noise sources the level of vibrations was also measured in the same time by means of the set of accelerometers inside each ship section. Radiation at discrete frequencies caused by low frequency hull vibrations, exited by the machinery is relatively easily detected and must be reduced as much as possible. The radiated underwater noise spectra show high-level tonal frequencies originated from propellers and also main engines. They varied with speed of the vessel in a complex manner. Ship's service diesel generator creates series of harmonics which amplitudes and frequencies are independent of ship speed. The paper documents series characteristics of the surface ships radiated underwater noise data which are discussed in details.

INTRODUCTION

The modern system of underwater observation based on passive watching of changes in the underwater acoustic field provides large possibilities with respect to increasing the safety in possible cases of its being threatened, especially nowadays with a real spectre of terrorist activity.

Means of underwater observation make it possible to detect, identify and classify sources of acoustic waves, and so - of all dynamic objects, with application of the passive technique; these means are therefore undetectable by possible threat factors.

One of the basic factors that can constitute potential threat is a mobile weapon, carried by objects sailing on the water surface and under water.

The content of the present work is focused on a certain way of interpreting underwater acoustic disturbances generated by objects of classic propulsion. Particular attention has been devoted to acoustic disturbances of small and medium frequencies propagating in a shallow sea.

CHARACTERISTICS OF A VESSEL'S UNDERWATER NOISE

The acoustic field of sailing ships changes along with the change of sailing speed and is bound with the mechanical activity of wave sources mounted in the ship's hull (main engines, current generating sets, gears, pumps, shafts, pipelines, ventilation channels etc.) and of hydrodynamic sources like the ship's propeller, the hull's flow around [3,4].

The identification of sources of underwater noise generated by the moving vessel, with various devices mounted on her, is a complex subject and continues to be an object of systematic research [1, 2, 5]. In the structure elements of the ship the propagating vibration energy interferes with acoustic waves originating from various sources, which makes their identification even more difficult.

A method of identifying the vessel's underwater noise is a penetrative examination of its spectrum. From measurements carried out, some characteristic components can be singled out, which are strictly bound with the working of mechanisms and devices mounted on the vessel. The continuous spectrum, which reflects the work of the cavitating ship propeller, turbulent flows in pipelines, ventilators, friction in slide bearings etc. also constitute an object of interest. In practice, it is difficult to identify underwater noise. The vessel's own noise "sums up" with technical noise originating from remote ships' environment, the shipyard industry or the working of a port. There is also noise of natural origin: wave motion, wind and rain. The identification of acoustic spectrum components may be made even more difficult by the fact that various ship devices may be sources of waves of similar or identical frequencies. Identifying the propagation of waves contained in the continuous spectrum of a ship in motion is significantly more difficult to interpret. The hydroacoustic waves coming from cavitating screw propellers, the hull's flow around, turbulent flow of air and liquids in a vessel's pipelines propagate in a wide frequency range. Apart from that, numerous transient processes generate acoustic disturbances, which are difficult to interpret [3, 4].

This work presents results of research on the underwater noise of a moving ships registered by means of the measurement range. During measurements the ships move on set trajectories through the measurement area on a course and counter-course at constant settings of the vessel's propelling system. The set dynamic quantities of the ships reach a minimum of 300 meters before the detectors and do not change it on a section of at least 600 meters (300 meters behind the measurement antenna). A constant recording of acoustic pressure is performed in a certain distance interval before the ships bow and behind the stern. Information obtained in this way permits to characterise the underwater disturbances of a given ship in a good way.

The unit selected for presentation was the one that sailed through the measurement range with a working main engine at rotation speed n =12.5 [1/s] and deflection angle of the propeller blades equal to 3˚, 4˚, 7.5˚. With these settings, the vessel reached the sailing speeds 6, 8, 12 [KN]. The passages for this ship have been presented on spectrograms in Fig.1.

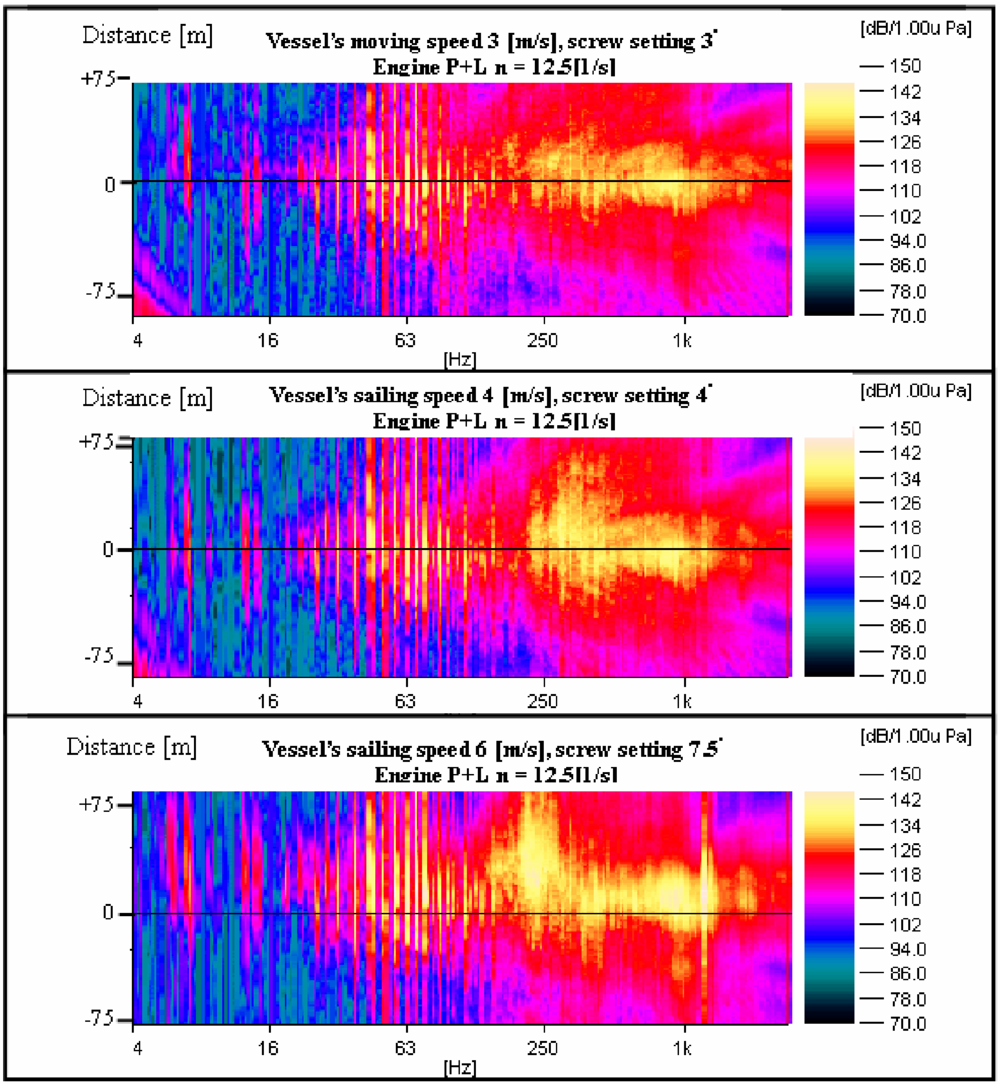

Figure 1 – Spectrogram of underwater noise obtained during testing a vessel at rotation speed of main engines n = 12.5[1/s] and respective screw settings 3, 4 and 7.5˚

These characteristics consist of 299 spectra registered every 203 [ms], with resolution 1/24 of octave in the range from 345 [MHz] to 2.818 [kHz]. The applied software settings made it possible to register and analyse the courses, duration time 60.73 [s] of underwater noise. On the spectrograms presented the frequency range has been narrowed from 4 [Hz] to 2.8 [kHz], and the registration time after transformation has been presented as the distance covered by the ship in motion. In places where "the loudest" part of the sailing unit was above the receiver, spectra have been selected out of the spectrogram which are presented in Fig. 2

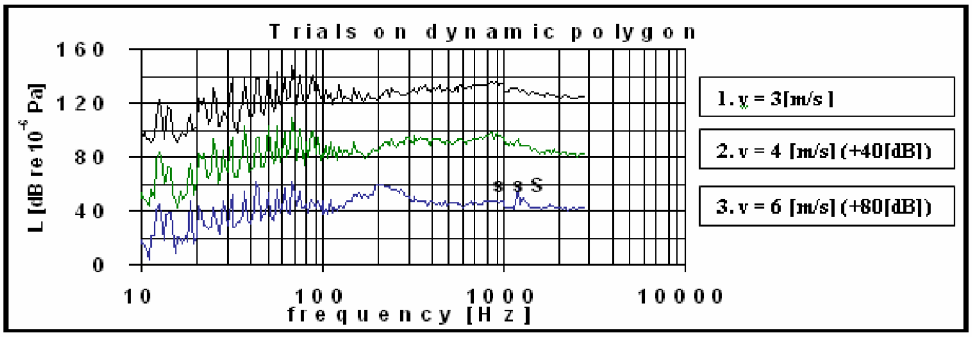

Figure 2 – Spectra of underwater noise (made at locations marked with black lines on the spectrograms)

Where: 1- spectrum obtained from spectrogram 1 made at the speed 3 [km/s],
2- spectrum obtained from spectrogram 2 made at sailing speed 4 [m/s] (signal damped by 40 [dB]),
3- spectrum obtained from spectrogram 3 made at sailing speed 6 [m/s] (signal damped by 80 [dB]).

Two images are visible in these figures. In the range up to about 100 [Hz] we can locate characteristic spectrum components related to work of the propelling systems. The technique applied, however, made it difficult to identify these acoustic waves. This is why in order to characterise them more accurately, the analysis of the first area was performed using filters with constant bandwidth and resolution 0.25 [Hz].

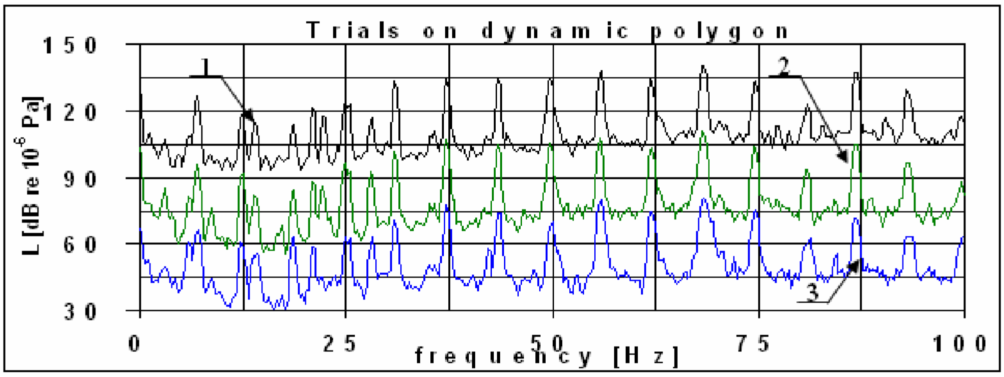

Figure 3 – Spectrum of underwater noise registered with rotation speed of main engines n =12.5[1/s]

Where: 1- spectrum made at speed v = 3 [m/s] and screw setting 3°,
2- spectrum made at speed v = 4 [m/s] and screw setting 4° (signal damped by 30 [dB]),
3- spectrum made at speed v = 6 [m/s] and screw setting 7.5° (and screw setting 60 [dB]).

The other area reflecting the changes in screw setting in frequency range from about 150 [Hz] is different for particular spectrograms.

PROPAGATION OF ACOUSTIC WAVES GENERATED BY A MOVING WAVE SOURCE IN A SHALLOW SEA

During underwater research on acoustic disturbances consisting in determining 3-D noise characteristics in the system of frequency, distance, intensity, there were observed characteristic lines bound with energy concentration, which assume the shape of hyperboles, where the frequency axis is one of the asymptotes.

During detailed research made for ships of three classes, with various main propulsions (compression-ignition engines and turbines) on various measurement depths and different sailing speeds, there could be observed numerous characteristic lines visible both during the vessel's approaching and sailing away from the sensor. The characteristic lines represent locally higher densities of acoustic energies with specific features of wave propagation in a shallow sea. These lines are more visible when the way covered by the vessel is longer. The spectrograms with the discussed area have been shown in Fig. 4

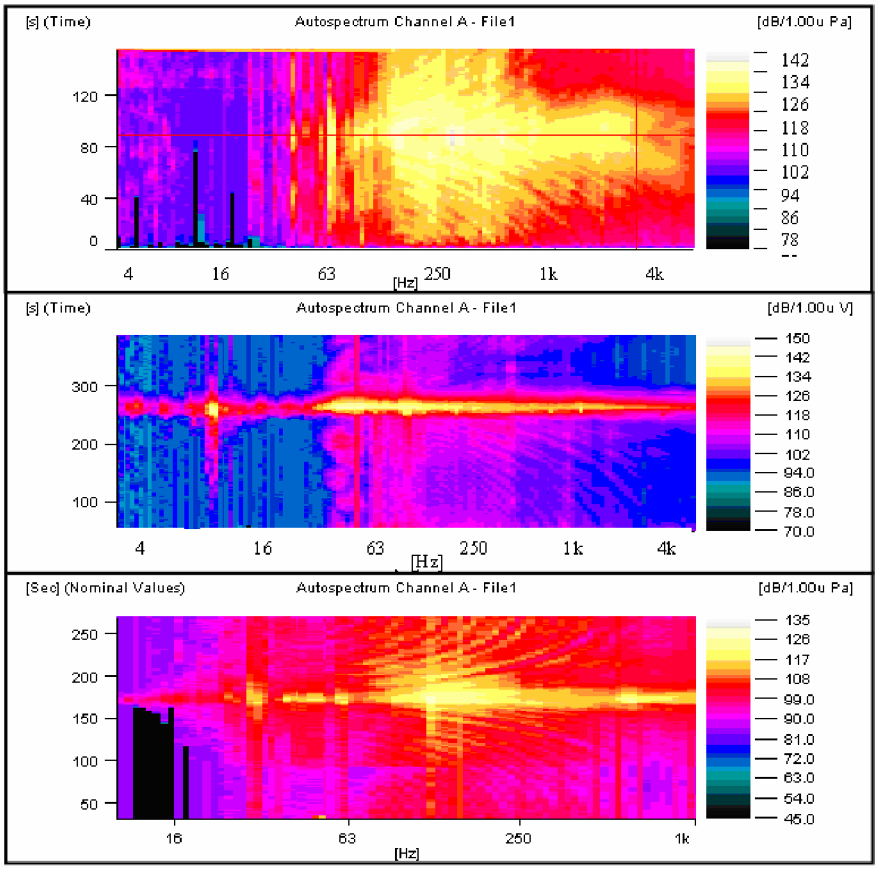

Figure 4 – 1. Spectrogram obtained during testing the ship for detectors established at the depth h = 10 [m] (measurements made at sailing speed v = 6,5 [m/s]).
2. Spectrogram obtained during testing a turbine-driven sailing unit on a mobile polygon established at the depth h = 10 [m] (measurements made at sailing speed v = 4,5 [m/s]).
3. Spectrogram obtained during testing a sailing unit on a mobile polygon established at the depth h = 27 [m] (measurements made at sailing speed v = 7,5 [m/s]).

Local reinforced areas (rays) visible in the spectrograms are connected with the propagation of acoustic waves of various lengths in a shallow sea. In order to explain this phenomenon, a simulation description of these waves was carried out. To simplify the model, measurement depth h=20 [m], was assumed, velocity of sound propagation in water $C_{śr}$=1450 [m/s], and the medium was assumed to be lossless.

In the simulation suggested rays were determined, whose waves of various length are reflected from the medium limits. A numerical code was worked out for the purpose, in which variables of source-to-sensor distance were determined for these waves. It was assumed for the calculations that the maximum wavelength able to propagate in this depth was 40 [m]. The calculations were made for waves in the length range from 0.1 [m] to 40 [m] with resolution of every 0.1 [m]. As in real conditions measurements of underwater noise are registered before and behind the ship, a correction was made in the code, which made it possible to determine propagating rays when the vessel was approaching the measuring area.

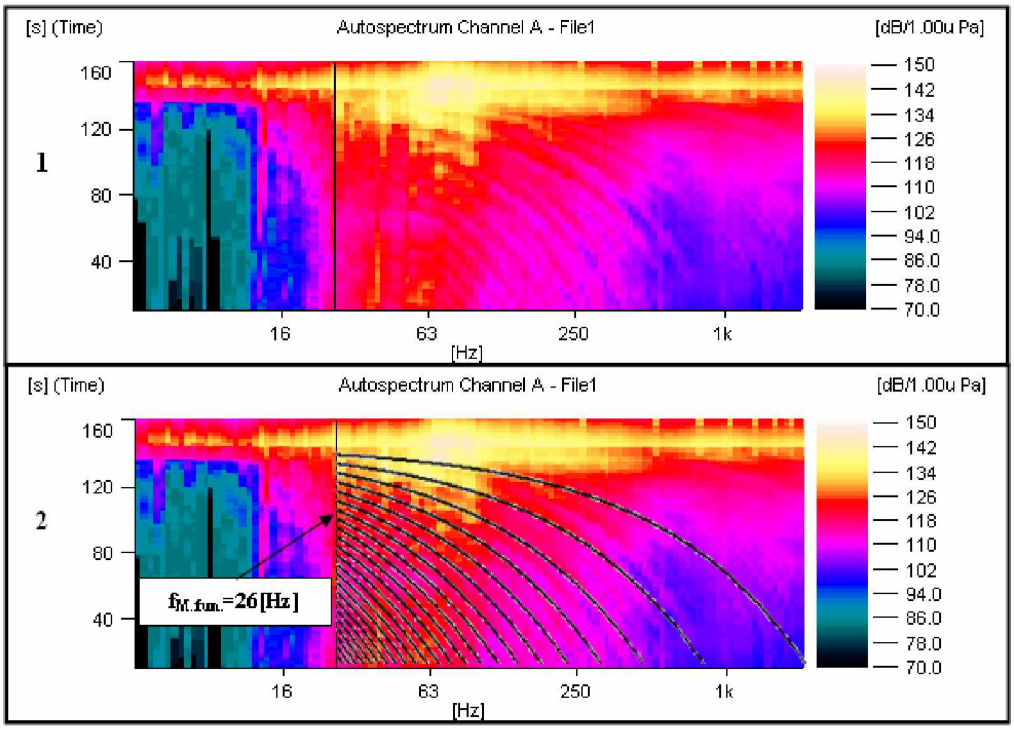

Figure 5 – Spectrogram obtained during the vessel's approaching the range (measurements made at speed v = 7,5 [m/s] at the depth h = 28 [m])

Where: 1- spectrogram without net,
2- spectrogram with overlaid net obtained from simulation.

It can be seen in the spectrogram with overlaid net that the presented rays are connected with the formation of modes in the water medium. The distances between these modes can be calculated theoretically or read from the spectra made.

An object moving away from the log was selected for the research. The applied analyser software made it possible to watch spectra registered every 1 [s] in the frequency range from 4 to 1600 [Hz] with 4 [Hz] resolution. An example of a spectrogram obtained from this research has been presented in Fig. 6. The time axis is presented as the distances of the vessel from the acoustic sensor. Waves of frequencies 160, 200 and 250 [Hz] have been marked with cursors in the figure. In the places marked, sections were made of the spectrogram along the distance axis. These results were compared with results obtained from theoretical calculations.

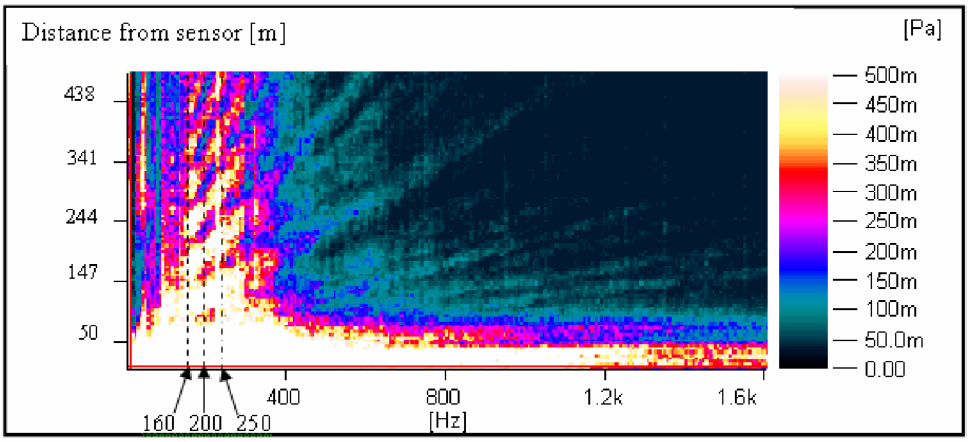

Figure 6 – Spectrogram obtained during the vessel's moving away from detectors (measurements made at sailing speed v = 4,7 [m/s] at depth h = 11.75 [m])

The calculations made and the suggested simulation confirmed the assumptions about the formation of acoustic rays in the shallow water as a result of multiple reflections of waves with various lengths from the medium's limits.

CONCLUSIONS

It has been shown in this work that in a shallow sea it is possible to identify hydroacoustic waves attendant on the vessel's working propelling systems and auxiliary mechanisms. Extensive trials carried out have shown that on the basis of underwater noise measurements in most cases it is possible to identify in the hydroacoustic field structure of the vessel characteristic components connected with the work of main engines, shafts, ship propellers, and also from working generators. The applied method of identifying hydroacoustic waves connected with the work of machines and devices mounted on the ship, which consists in simultaneous measurement of vibrations and acoustic pressure, made it possible to accurately identify the frequency of these waves.

Research on continuous spectrum done for various vessels at various measurement depths has shown that in a shallow sea it is possible to describe theoretically the propagation of the waves.

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