RANGES AND EQUIPMENT FOR THE MEASUREMENT OF THE SHIP'S UNDERWATER SIGNATURES

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Controlling unwanted signatures on warships is a most important effort for ship designers and naval operators. A great attempt is considerate in this field in many countries such as the USA, Germany, Sweden, Norway and in Poland as well. This paper presents ranges and techniques for the investigation of the underwater physical fields radiated by different surface ships and submarines. The Polish Naval Academy and the Naval Test and Evaluation Ranges (NTER) check and next decrease generated by the ship's physical fields. These underwater signals can be hydroacoustic, hydrodynamic, electric, magnetic and seismic in nature. In order to have good quality measurements, there are land and sea installations, platforms on trucks, and what more a special laboratory aboard the ship. The Ranges also have a fixed and transportable multi–sensor equipment installed in a single module. This apparatus is now being used both for the measurement and for the gathering of scientific data which are next further research and analysis.

INTRODUCTION

There are different sensors for the sea mines' activations. One is the Influence Sensing Device (ISD), the electronic component that monitors changes in the underwater environment in order to detect enemy surface ships and submarines and decides whether they are close enough to damage via the mine's blast effects. These detection devices can use one sensor or a combination of influence sensors. Pressure, magnetic, acoustic, and seismic are four types of influence sensing devices often used to detect changes in the mines' surroundings. If the change goes above definite levels, the sensing device responds and starts a sequence that explodes the mine.

From the time when the Civil War began, naval mines have been responsible for the sinking or damage of more vessels than any other single weapon system [1]. The sea mines have been used successfully in many old and new conflicts over the last two hundred years, that is from the American Civil War, the Russian – Japanese War and both World Wars.

After World War II sea mines have been also used in Korea, Vietnam, Suez Canal, Falklands, Nicaragua and lately during the Persian Gulf.

During the Second World War new technology was being applied either to reduce to a minimum the magnetic signatures, or to install compensation techniques that would cancel out the effect of such signatures. Development in new technology was stimulated to decrease losses suffered by merchant and naval shipping from magnetic mines. Reducing the effect of a ship's magnetic signature was achieved mainly through special magnetic treatment facilities (deperming). The navies also had to build new types of ships which were minesweepers and minehunters in order to hunt after the mines. For the period of the last thirty years, mines have also been used against worldwide naval forces deployed to protect the western world commercial shipping. Currently terrorists and hostile governments often provide the secret operations with use of sea mines, because they are invisible weapons which wait silently for the target to approach [1].

Offensive mining is extraordinary for the cost – effectiveness, mainly regarding the disproportionate response required from the potential victim. The laying of archaic mines in the Persian Gulf in the late 1980s, from variety of non-military devices caused severe trouble to shipping and next an extensive and expensive multi-national mine clearing operations.

In addition, the conversion of conventional airborne bombs to relatively sophisticated sea mines, using a small switch equipment, is now within the power of many countries.

1. SHIP'S SIGNATURES

The art of signature management lies in the ability to obtain the right balance between the different physical field's signatures, which is presented in Fig.1. There are here levels of a ship's magnetic, acoustic, hydrodynamic and seismic signatures.

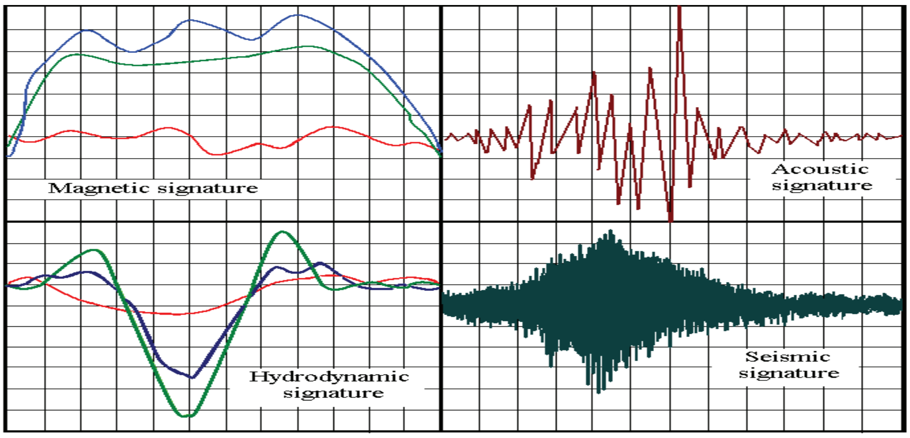

Fig.1. Characteristic profiles of the underwater multi-influence signatures associated with a moving ship. They were measured with the use of equipment made by the Naval Academy.

The relative importance of different types of ship's signatures can be expected to change with time, as new and more sensitive detectors and more sophisticated signal processing techniques become available. The object of signature management is to achieve the best combination of outside shape, coatings and internal treatments which will give the desired overall at an acceptable cost.

The problem of underwater noise is caused by strongly packed high-powered equipment, confined in a small metal or plastic vessel. Shipboard noise is generally created by poor or improper vessel acoustic design. In average speeds, the noisiest piece of equipment on any ship is usually its main engine. Being a reciprocating machine, the diesel is very loud and also generates a great deal of vibration. All ships, even quiet ones have noisy or even extremely noise, engine rooms, that is often above 100 dB (A). Problems occur when a vessel's design provides transmission paths for noise to travel from the noisy engine room through the hull into the water.

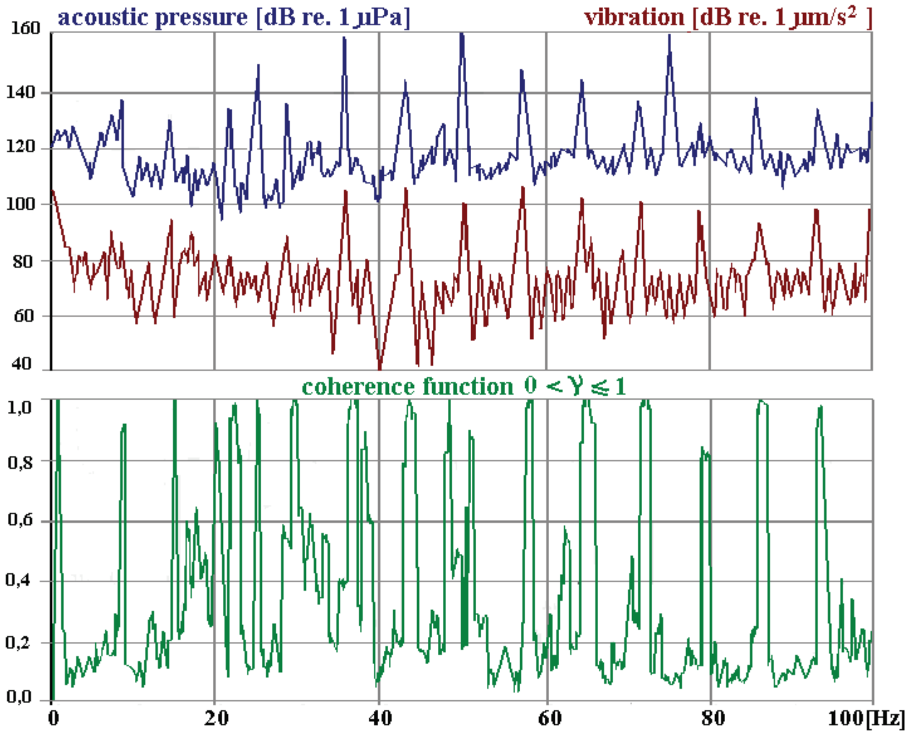

Fig.2. The ship's sound pressure level high-resolution keel aspect narrow-band power spectrum and the vibration plus coherence function of these two signals.

At low ship speeds the ship's diesel generates produce discrete lines, which dominate in the spectrum. The main component is a strong discrete line at 25 Hz and its harmonic at 50 Hz. These frequencies are from rotational speed of auxiliary machinery components. Because our diesel generator was power by a four-stroke six-cylinder diesel engine, that vibrated with firing rate equal to 37.5 Hz. Therefore we have two main lines at 25 and 37.5 Hz and their fundamental harmonics at 50 and 75 Hz. Those tonals are shown in Fig.2.

2. MAGNETIC AND ELECTRIC SIGNATURES

Magnetic sensors detect changes all along the Earth's magnetic field. When the hull of a steel ship disturbs the lines of instability of the Earth's local magnetic field a firing mechanism initiates the detonation of the sea mine.

Some signatures, such as the magnetic signature, have been the focus of significant attention for many years. Magnetic signatures are measured by passing the surface ship over a fixed degaussing range. The peak magnitude change though is very small in comparison with the natural background field, and it is a function of geographical location. The measured period of time is a function of the speed of the ship and its length, and it is usually between 2 and 30 seconds. There is also a much smaller higher frequency component of less level than 0.1 nT. Fig.3. shows the magnetic field of an undegaussed moving ship.

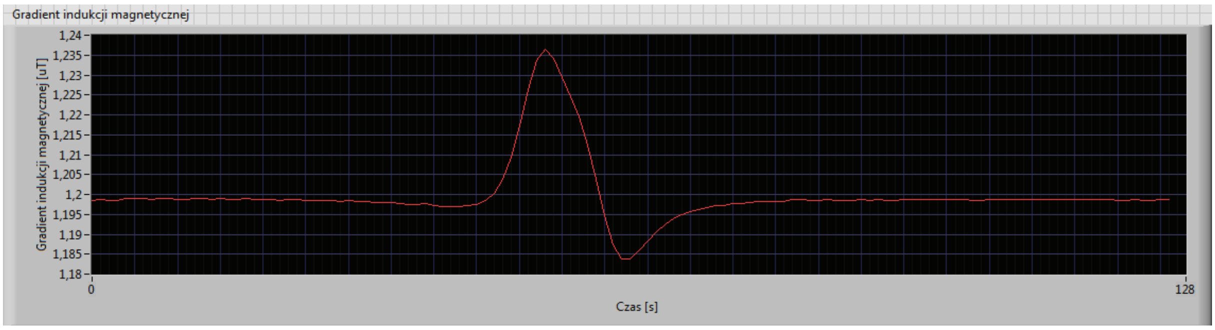

Fig.3. The magnetic field of an undegaussed running ship.

However the best solution for the magnetic measurement is the three-axis magnetometer which is presented in Fig.4. The magnetic signature includes two components. First, the permanent magnetization which is a function of the ship's size, material, location and orientation during construction. It can be minimized at the time of deperming. Second, the induced magnetization which is dependent on the current geographical position and orientation of the ship in the Earth's magnetic field. These part of magnetic field can be reduced by passing currents through multiple coils mounted in three directions and spaced around the ship's hull.

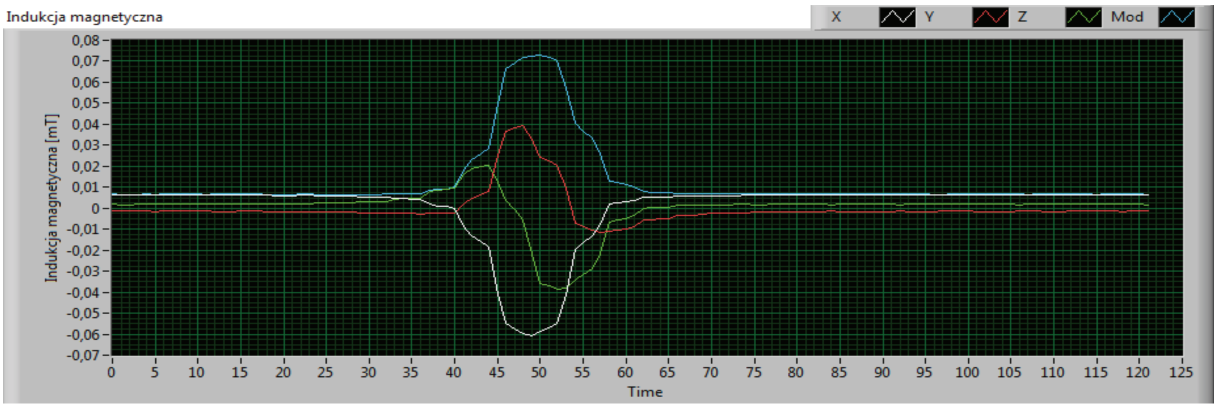

Fig.4. The magnetic fields of an undegaussed running ship from three-axis marine magnetometer. The signatures were determined by IGLOO module.

Treatments of a ship are called deperming, it engages putting the ship inside a collection of coils or placing an arrangement of coils around the ship, and then passing a powerful electric impulses throughout the coils to generate a magnetic field in opposition to the magnetic field of the ship. The disadvantage of deperming is that it is not stable, and the ship must be checked periodically once during three or six months.

In a modern surface ship the currents must be changed automatically with geographical location and with the heading of the ship. Alternatively active degaussing coils are built inside the warships during construction to provide the changes of magnetic field correction. The coils are constantly fed with electric current provided from unique computer-controlled generators to create an opposing magnetic field. That field is constantly matched when the vessel's changing magnetic field during it's sailing across the sea.

The electric signature takes place from the modulation by the ship's rotating machinery of the small currents generated by the immersion of dissimilar metals, such as the steel hull and bronze propellers, in an electrolyte, that is inside the salt water. Active cathodic protection methods also contribute to the produce similar effects.

Atmospheric electric noise is also coupled into the sea environment. This is dominated at low frequencies by the nearly continuous occurrence of worldwide lightning storms, characterized by the Schumann resonances. Furthermore, the electric noise from the land is propagated along the sea floor and upward into the water. However, the electric field detectors must also be capable of handling extremely small signals.

3. HYDROACOUSTIC SIGNATURE

Underwater acoustic sensors of the mines use hydrophones to detect propellers, main engines, auxiliary machinery and other equipment that make noise as the ship moves through the water. That noise must meet a fixed acoustic signature for the firing mechanism to initiate.

Surface ships and even more notably submarines generate high levels of the underwater radiated noise that is detected and tracked by passive sonars, sometimes hundreds of miles away from the hydrophones. Hostile naves also use the underwater noise signature radiated by different vessels not only for detection but also for classification of targets [4]; sometimes is enough to take into account the sound pressure levels that are shown in Fig.5.

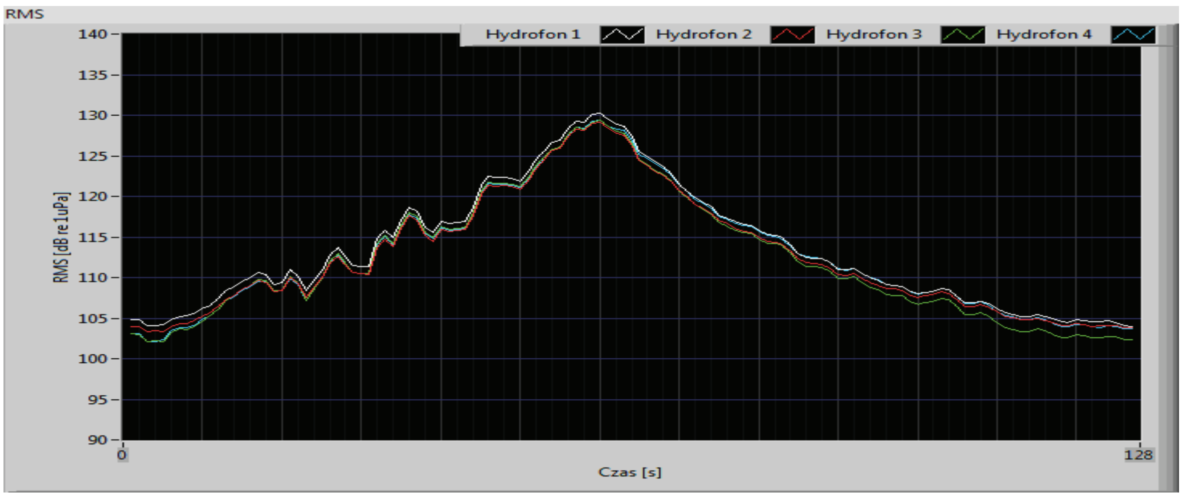

Fig.5. The sound pressure levels of a vessel recorded by IGLOO module that use the digital technique.

Acoustic signature management these days is a highly complex subject taking on such widely different disciplines as: hydrodynamics, structural dynamics, vibration, hydroacoustic, acoustic, machinery noise, sonar platform design, computational modeling, polymer physics, and chemistry. This multidisciplinary approach is very useful in addressing the three acoustic signatures that largely affect the acoustic stealth of a vessel [4].

The acoustic results of World Ware II investigations were described in a textbook untitled "Physics of Sound in the Sea" by Urick. Next he wrote a famous book "Principles of Underwater Sound", which was compendium describing radiated noise from many merchant and military vessels [2]. Also Ross considered the noise of different ships and trends in ship size and powering. He also wrote a textbook that described the essential features of vessel's noise [3]. Donald Ross examined the noise of many ships and trends in the ship size and powering [5]. He wrote in this textbook about the speed and power dependence of the radiated noise of surface ships.

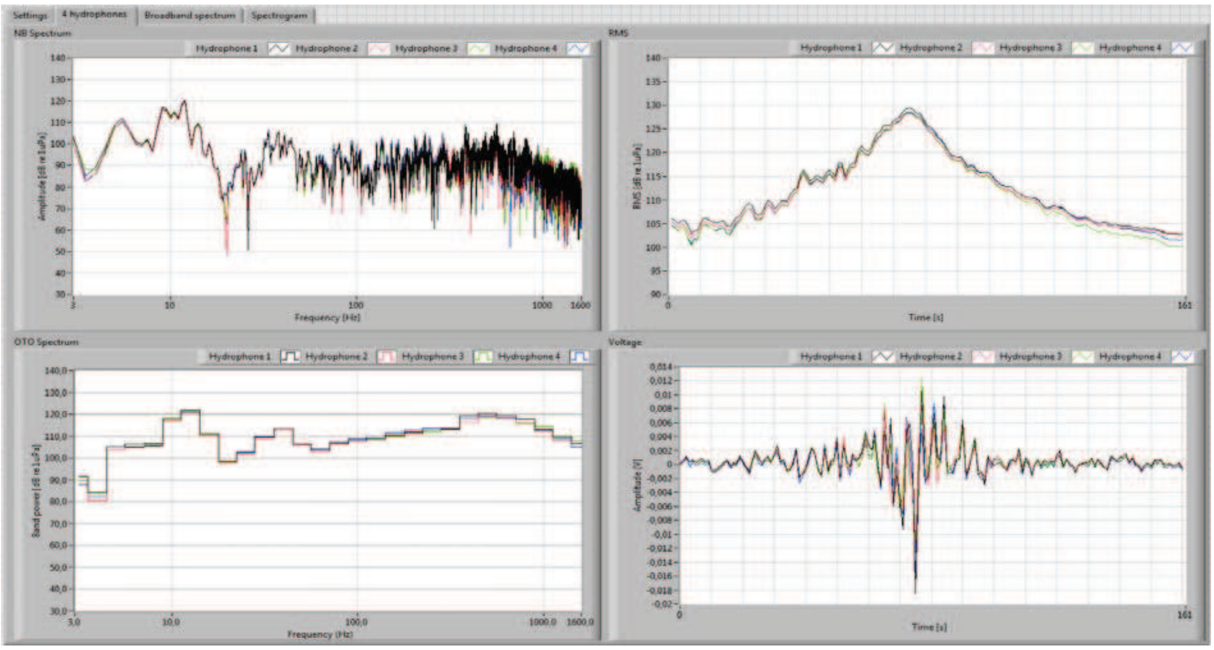

Fig.6. The graphs show the underwater acoustic signatures generated by a ship. They suit AMP-15, that is the NATO stanag requirements.

A lot of of the printed ship noise measurements, were made with third-octave bandwidth analysis, that is very wide for separation of the individual spectral components of ship radiation. However it fulfill the NATO AMP-15 stanag requirements that's why it is presented in Fig. 6. The data are frequently obtained in the shallow waters, so their levels can not be representative of the free-field values, particularly at low frequencies.

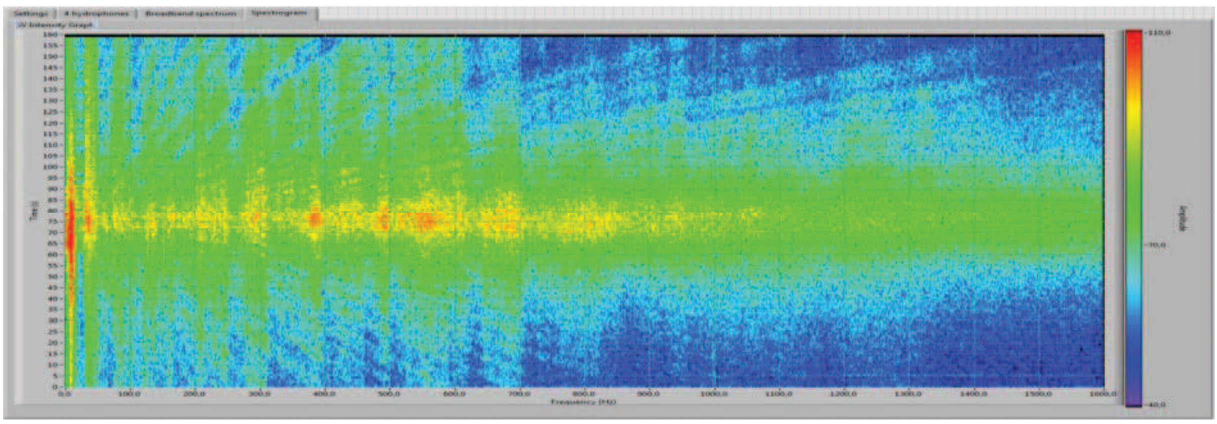

Fig.7. The hydroacoustic field spectrogram of a running surface warship.

Fig.7. presents hydroacoustic pressure spectrogram which was recorded from the Reson hydrophones installed on three-pod module. The high values of the pick pressure was

sometimes over 20 kPa at 1 m in some cases. The underwater acoustic transmission losses are geographically dependent; they are a function of the sound speed profile, the bathymetry, and the physical properties of the sea water.

4. HYDRODYNAMIC SIGNATURE

When hydrodynamic sensors detect a change in pressure at a certain level the mine's switch closes up the firing circuit, enabling electric current to pass through from the firing battery to the detonator. The detonator explodes, setting off the major charge in the mine. Achievement of this sequence takes a fraction of a second. Hydrodynamic detectors identify the pressure changes in the water caused by a passing ship as it displaces a given volume of water beneath its hull throughout the course of its passage over the submerged mine.

The pressure signature arises from the reduction in pressure associated with a fluid moving over a surface – Bernoulli's principle. It is limited to the vicinity of the ship. In shallow waters the sea floor pressure rises slightly as the bow passes and then drops below the original level. It rises again as the stern passes and then returns to normal. The magnitude and duration are related to the hull shape, the water depth and the ship speed. Fig.8. shows the level of pressure change from a moving ship.

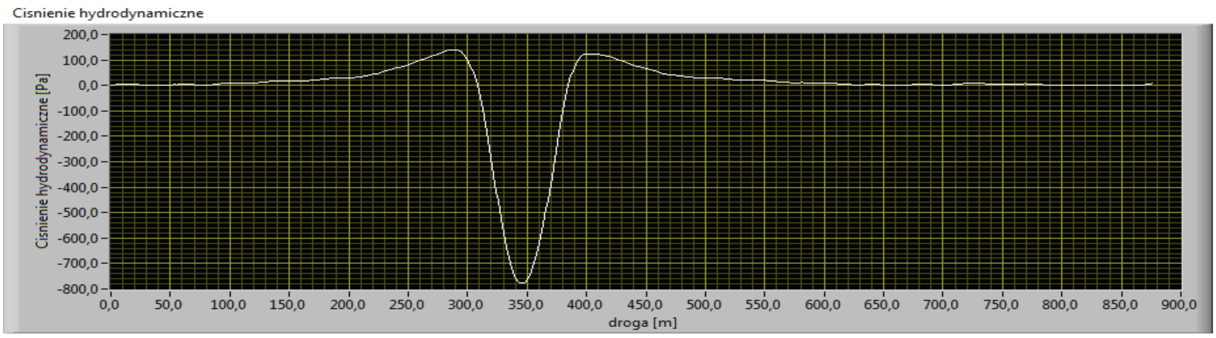

Fig.8. A signature of the hydrodynamic pressure of a running ship.

The ship-induced fluctuations are superimposed on the nominal static depth pressure at the sea floor and on the natural perturbations of the sea, that is swells and waves. Waves and swells, typically with periods between 1 and 30 seconds, can mask the ship induced changes of similar duration. Higher frequency, lower magnitude variations of less even than 1 mm may also arise from wind wavelets and from passing ships.

For precise data interpretation, the actual depth of the water at the time of measurement is needed. Therefore, for measurement in 30 m of water, a dynamic range in excess of 90 dB is required.

The hydrodynamic shape of the ship's hull in water is also subjected to close examination in order to minimize any signature that can be created by its running through the water.

5. SEISMIC SIGNATURE

Seismic sensors also use analogous to sound detection technology to initiate the mine's firing sequence. The extremely sensitive seismic sensor within the mine is designed to detect small movements of the mine's container. This feature is unlike the acoustic sensor where the hydrophone picks up the noise signatures.

Acoustic waves can propagate in the sediment such as mud, sand and rock, which contain the seabed. In these materials, the waves are typically understood as seismic waves and can be measured as disturbance in the particles that make up the bottom. A high sensitivity seismic transducer has been incorporated to detect the seismic influence. The seismic sensors are composed by one or three-axes accelerometers. Yet we sometimes use one-axe accelerometer that described our seismic signature shown in Fig. 9.

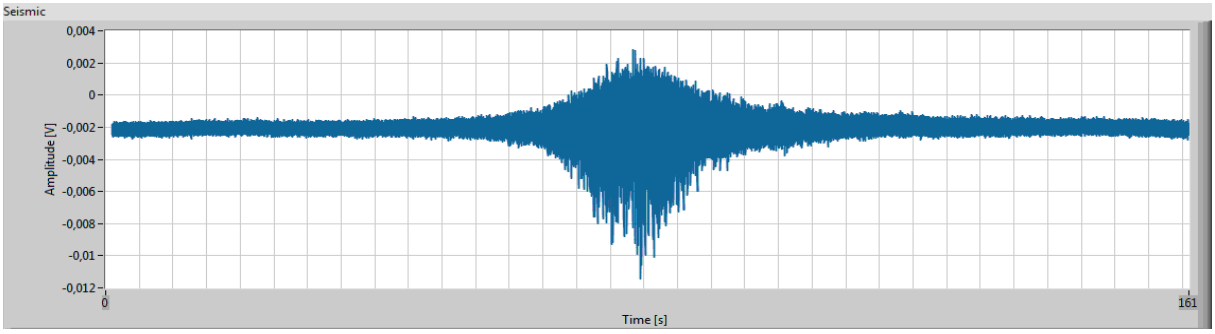

Fig.9. A signature of a seismic field of a running ship.

Some sensors are the triple-axis and are connected to an offshore data acquisition unit via conventional cables and underwater plug connections. This unit converse the sensors signals into corresponding data messages and transmits them via the transmission path to the shore-based data processing system. In addition the system performs all control and monitoring functions during the ranging process.

6. NAVAL TEST AND EVALUATION RANGES

For over forty years, the Polish Naval Academy and the Naval Test and Evaluation Ranges (NTER) have been developing the technology and procedures in order to measure the influence fields generated by different underwater objects. The weakness of individual vessels to the detection and damage by an influence mine can be reduced, first by measuring the ship's underwater signatures and next by implementing a suitable signature reduction strategy.

The sophisticated modern sensors and the control equipment are required to measure various signatures of warships and to reduce them to the lowest level possible. It is done in order to reduce the risk of detection and lower signatures vulnerability to underwater weapons. The attention should be paid to reducing a vessel's signature to a minimum, both at the design stage and during construction. A ship's signature similar to the humans fingerprint allows it to be detected and indentified.

The ranges are so specialized, and using such advanced technology to make the subtle measuring that only a few corporations are able of manufacturing them. They are often connected with technical universities - in Poland with the Naval Academy and Gdansk University of Technology. The requirements are for fixed and mobile platforms that can be deployed in the sheltered waters for the documentation of hydroacoustic, pressure, seismic, electric and three-axis magnetic fields. Measurements are required of the static and dynamic signatures associated both with the ship influences and with the background environment. The whole equipment is modular in structure, transportable and easily arranged in the sheltered waters.

Calm, deep waters are necessary for good quality measurements. Shelter from the wind and sea improve the signal-to-noise ratio. This signal-to-noise ratio for the whole spectrum data should be 20 dB or greater [6]. Data quality are also improved by making the measurements distant from man-made interferences such as the noise from the industry. After that data quality have been also improved by making the measurement remote from the noise arising from the commercial and residential regions. We must also isolated the ranges from the 25 and 50 Hz tonals which are typical to the European electric power network [7].

When the range is installed, the sea bottom must be relatively flat to simplify the mathematical modeling of the measurements. Sand, stones or clay sea bottom composition are preferred for our purpose. Waves and swells furthermore induce variations which can pollute the measurement. The measurement can be spoiled by a propeller turning in the water at high speed, because this develops an area of low pressure behind the trailing edge of the blade. This effect causes the water to vaporize, which creates a bunch of small bubbles.

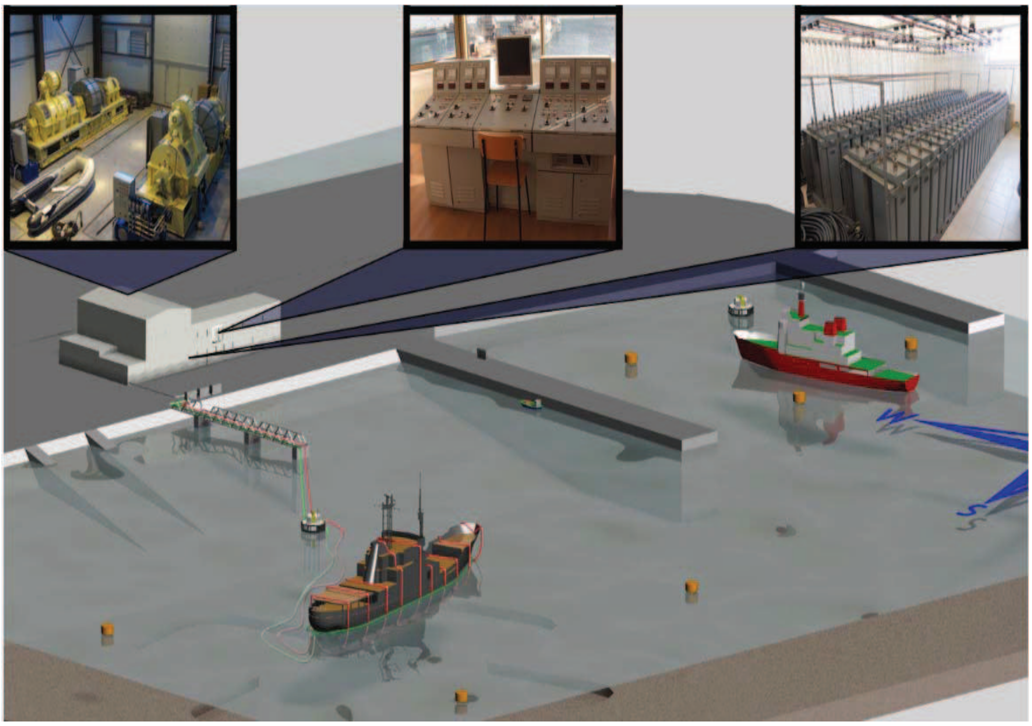

Fig.10. The control building, magnetic range equipment and treatment facilities.
The ship is rigged with X-solenoid (red) and Z-loop (green) in deperming process.

The Gdansk University of Technology helped to establish some modern equipment in the Magnetic Degaussing Range shown in Fig.10. Wide planning is being done to take full advantage of the information to be obtained from the warship noise measurements. This is done because of the high cost of diversion of the vessel from her normal sailing and because of the large amount of radiated noise data required. A set of measurement criteria have been developed to help ensure reliable data quality.

Underwater acoustic ranges for static and on dynamic measurements of submarines are among the largest and most sophisticated tools worldwide and they must be located in the deep and calm waters. In such condition the mean wave height has to be less than 0.5 m, with wind speed less than 5 m/s, as a result the ambient noise level is low. The measurements were carried out in such conditions during late spring. The sound speed profiles at the time of our experiments were typical in this period. Their were smooth and gradually decreasing gradient without mixed layers.

In order to reduce noise from surface ships and submarines we employ different noise isolation systems. We used a wide range of techniques, including double-elastic mounting systems. They were developed for the case of the diesel engines, where high fundamental source levels had to be reduced.

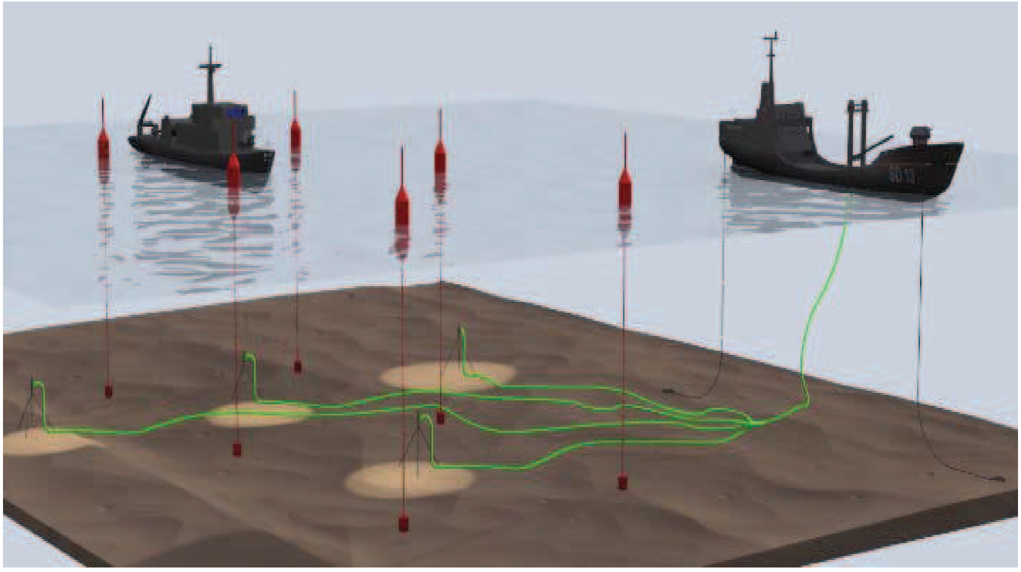

Fig.11. The ship's physical field measuring system
aboard a special laboratory ship for mobile distant examination.

More and more serious attention has to be paid to the secondary transmission paths in the design of such advanced isolation systems. What more different navies seek active control techniques, which are at present under development to improve the high degree of isolation, which can already be achieved through well-balanced, passive isolation treatments.

ACKNOWLEDGEMENTS

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