Underwater radiated noise of ships' machinery in shallow water

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Abstract: - This paper is pertaining underwater noise created by ship's machinery. The number of ships on sea is continuingly increasing. The size of the new constructed ships is increasing and the ship's machineries also. Thus the pollution caused on the marine environment becomes a big issue. Acoustic pollution is a domain in which little is known. Our research is orientated on determining the environmental underwater noise on the North-West coast of the Black Sea and recording and analyzing the noise generated by merchant ships. In order to process the signals in the time-frequency spectral analysis, we used the Sort Time Fourier Transform; this method gave us good data about the frequency variation with time.

Key-Words: underwater noise of ship, spectrogram Short Time Fourier Transform, Fast Fourier Transform analysis.

1 Introduction

Human activity in the marine environment is an important component of the total sea acoustic background. Sound is used both as a tool for probing the sea and as a by-product of other activities.

Noise from artificial sources vary in space and time, but may be grouped into general categories:

a) large commercial ships;
b) military sonar;
c) ship-mounted sonar;
d) offshore drilling implements;
e) research sound sources;
f) small ships.

At low frequencies (5 to 500 Hz), commercial shipping is the major contributor to noise in the world's seas. The distribution of ships contributes to the background noise over large geographic areas [1]. The sounds of individual vessels are often spatially and temporally indistinguishable in distant vessel traffic noise. Noise from vessel traffic at high latitudes is propagating over large distances because in these regions the sea sound channel (zone of most efficient sound propagation) reaches the sea surface.

Vessel operation statistics indicate steady growth in vessel traffic over the past few decades [2]. There has been an increase both in the number of vessels and in the tonnage of goods shipped.

Among the many human-induced sources of low frequency sound in the marine environment, marine vessels (and particularly large commercial ships) represent numerous, widespread, and relatively loud individual sources of underwater noise. The exact characteristics of which depend on ship type, size, mode of propulsion, operational characteristics, speed, and other factors.

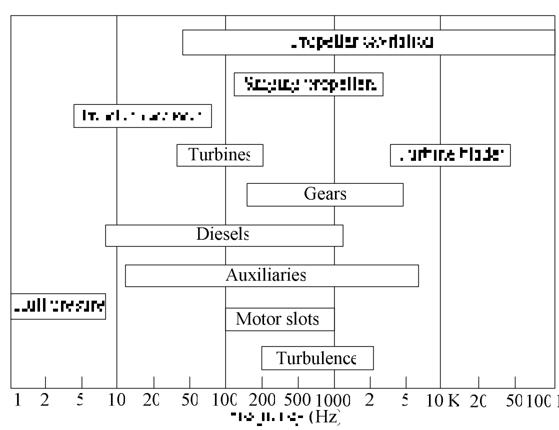

Fig.1 *Typical frequency ranges of different sources of ship noise*

Much of the incidental noise results from propeller cavitations, though onboard machinery and turbulence around the hull can also result in underwater noise transmitted underwater via direct or secondary paths.

Various vessel elements produce different frequencies, with low frequency sound generally travelling farther due to the physical properties of sound in water.

There are four main sound sources on a ship:

a)Machinery (main propulsion and auxiliary machines);

b) Propellers (or other forms of in-water propulsion);

c) Hydroacoustic noise generated by the flow of water on the hull;

d) Other noise generated within the ship, especially under the water line.

Each of these sources has a typical frequency band (see Fig.1) and exhibits different behaviour under different conditions. Most of the information is in the 10 Hz to 2 kHz range, although information also exists at other frequencies.

Under normal operating conditions, machinery noise is dominant over other sources in most ships. Different types of machinery can generate quite a variety of noise.

Diesel engines, the most common type of engine, have a number of cylinders and the firing rate of these will determine the dominant frequency of the noise generated. However, very slight imbalances always occur between the cylinders, and a small power peak is usually observed at the basic frequency of individual fittings [3]. By comparing these two frequencies, the number of cylinders of that particular engine can be estimated.

After engines, the next most significant sources of noise are the reduction gear boxes that make the coupling between the propulsion machines and the propeller shaft. Under certain circumstances, they may even produce more noise than the engines. The fundamental frequency corresponds to the number of teeth contacted per second. Some types of engines, such as electric, can work at the relatively low rotation rates of propellers, thereby forgoing the noisy reduction gears.

Noise generated by the ship's machinery reaches the sea water only after traversing its structure and the hull/sea interface. This transmission process has a huge impact on the sound.

Most of the noise generated by machinery is concentrated at the precise frequencies described above or at their harmonics. It is thus called tonal noise or narrow band noise, and appears as narrow peaks in the spectra of the ship's acoustical signature. As the operating conditions of the ship changes, different machinery will have different behaviours. The machinery associated with the main propulsion will generate noise with a higher frequency as the ship's speed increases, while many auxiliary machines, such as generators or pumps will not change their acoustical signatures [4, 5].

2 Equipment and methods

In this experiment we have used equipment from Bruel&Kjær: 3 hydrophones type 8106, data acquisition system LAN XI, laptop with PULSE 14 software, three 100 meters long cables, calibrator type 4229.

Hydrophone type 8106 is a wide-range, general-purpose transducer for making absolute sound measurements over the frequency range 7Hz to 80 kHz with a receiving sensitivity of −174dB re1V/µPa. The hydrophone is capable of withstanding high static pressure, the operational upper limit being 107 Pa. A built-in high-quality, thick-film, low-noise, 10 dB preamplifier provides signal conditioning for transmission over long underwater cables.

PULSE is Brüel&Kjær's platform for noise and vibration analysis. PULSE 14 is the latest release from B&K and the base measurement software is FFT analysis and CPB analysis [6].

Measurements were made on the west coast of the Black Sea between 14^{th} and 26^{th} of May 2010 on board of the *Mare Nigrum*, a research ship from the National Research Institute GeoEcoMar.

We made several recordings in different stations grouped into three profiles which can be seen in the map below (Sf. Gheorghe, Portita and Constanta):

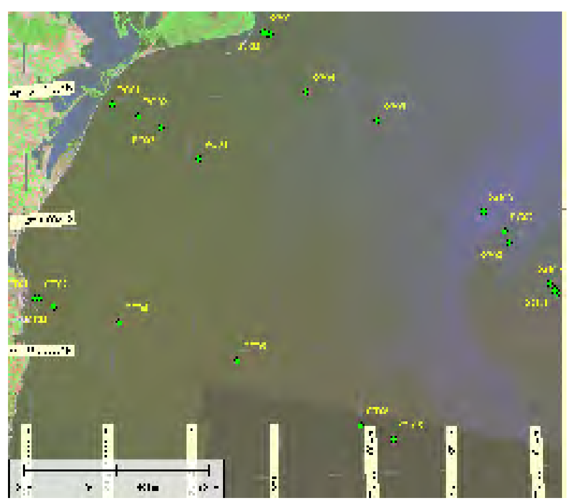

Fig.2 *The map with measurements positions on the NW coast of the Black Sea*

Measurements were conducted using three hydrophones in the same time deployed from the ship.

In this way we could record the acoustic signal on three depths simultaneously (see Fig.3). In order to minimize the effect of waves and current an array was constructed using a weight, a rope and a buoy.

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We tied a weight onto the rope and the buoy at the other end; the cables and hydrophones were attached on the rope; the weight was about 15 kg and the buoy, bicone shape, was chosen to ensure that the hydrophones would not move horizontally, but in the same time they would not be pulled out of the water.

A second buoy, ball shape, is used to indicate the array position.

In the positions indicated in the map we conducted three types of recordings:

- first we measured the noise generated by the ship in the proximity of the ship (2 to 5 meters from the hull); these recordings were made in a variety of situations: measuring only the noise generated by the diesel generators, either generators and the main engines; we have the opportunity to record the activity of a multibeam sonar.

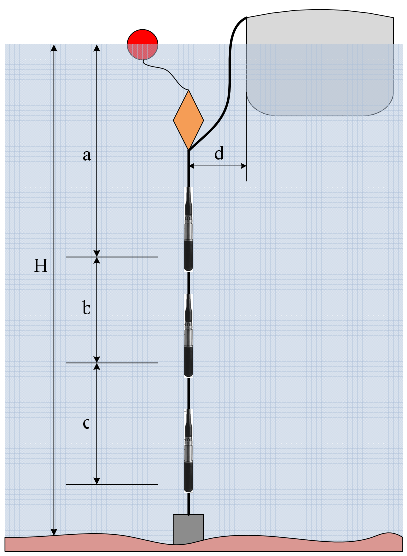

Fig.3 *The array used for recording the sound*

- second we measured the noise created by the ship's machineries at a distance of 1.5Nm from the ship; this was possible using the service boat. The equipment has autonomy of 4 hours which permitted us to make several recordings at different distances.

These recordings gave us information on sound propagation and acoustic signal attenuation.

- third we made measurements to determine the ambient noise level; these were made in open sea with no artificial noise source in presence.

For a better representation of the recorded signals in the time-frequency domain, we have used the Short Time Fourier Transform (STFT) spectrogram. The Short Time Fourier Transform is given by:

$$STFT(f,\sigma)=\int_{-\infty}^{+\infty} s(\tau)w(\tau-\sigma)e^{-j2\pi f\tau}d\tau \qquad (1)$$

where $w(t)$ is the window function (i.e. Hamming window function) [6]. This window is called the sliding window.

In STFT spectrogram method the sliding window splits the signal into segments and Fourier Transform for each segment, assembled into the final 2D matrix as data structure, is plotted in time frequency plane. The magnitude of STFT determines the power spectral density which can be expressed in logarithmic values:

$$P(t,f)=\left|STFT(f,\sigma)\right|^2 \qquad (2)$$

where $P(t,f)$ is the power spectral density (PSD) [7,8].

3 Experimental results

From the recording positions from the map we chose for this paper those notated with CT05 and PO04.

Fourier spectrum analysis was made in the frequency band 0-200 Hz, this being the normal working interval of diesel generator and the main engine. The STFT spectrogram was made in a frequency band 0-500Hz and the length of the signals was 524288 samples ($\Delta t = 11$ sec).

In the first position $43^o59'_0 N$, $29^o30^o_7 E$, depth was of 50 meters, sea state 2-3, wind speed 13 m/s, air temperature $16^o C$. The only machinery operating was a diesel generator. The depths of the hydrophones are 15m, 30m and 45m respectively. Distance from the ship's hull was 3m.

For each position we recorded three signals one for each hydrophone for a time interval of 11 seconds. In this paper we will present the results obtained from the second hydrophone.

On the ship the only operating machinery was a diesel generator. In the figures below we pointed out the moment of turning on the main engines. The results are analyzed with three methods: FFT spectrum analysis, STFT spectrogram and Discrete Wavelet Transform (DWT).

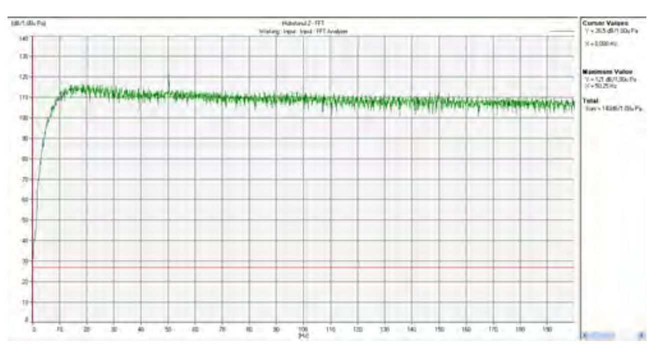

Fig.4 *FFT Spectrum of the noise generated by diesel generators 3m away from the ship's hull at turning on the main engines*

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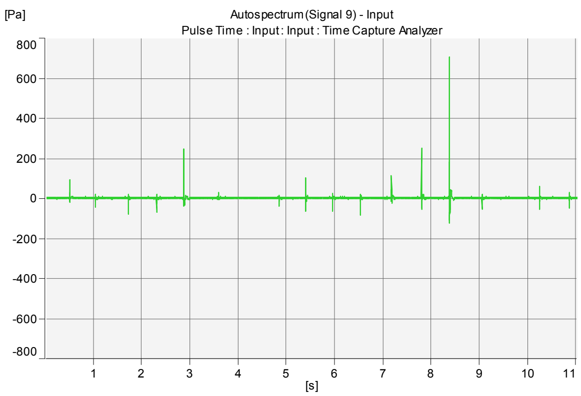

Fig.5 *Underwater noise generated by diesel generators 3m away from the ship's hull at turning on the main engines*

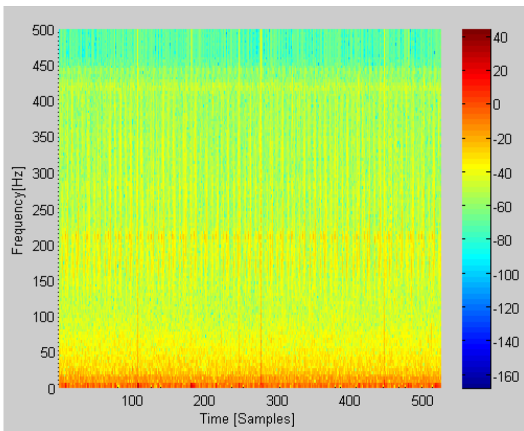

Fig.6 *STFT Spectrogram of the noise generated by diesel generators 3m away from the ship's hull at turning on the main engines*

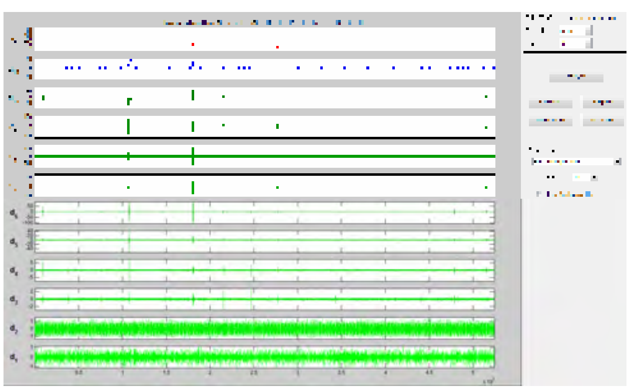

Fig.7 *DWT of the noise generated by diesel generators 3m away from the ship's hull at turning on the main engines*

The acoustic signal recorded was processed using Pulse14 and Matlab (Short Time Fourier Transform spectrogram and Discrete Wavelet Transform decomposition) and the result can be observed below.

Fig.8, 9 represents the FFT spectrum and STFT spectrogram of noise 5 minutes after the moment of starting the engines. One can notice that in the moment of starting the engines the noise raised on all frequencies. After 5 minutes of working we can notice peaks at 50Hz, 100Hz and 150Hz.

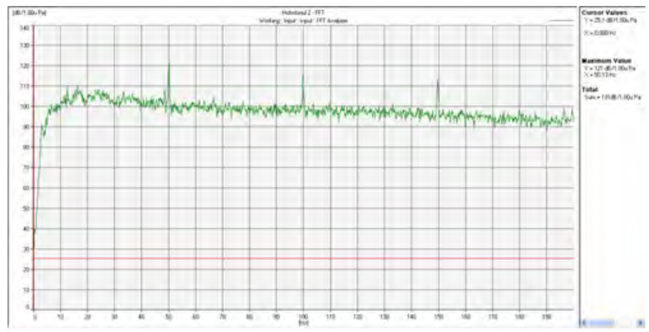

Fig.8 *FFT Spectrum of the noise generated by main engine and diesel generators 3m from the ship*

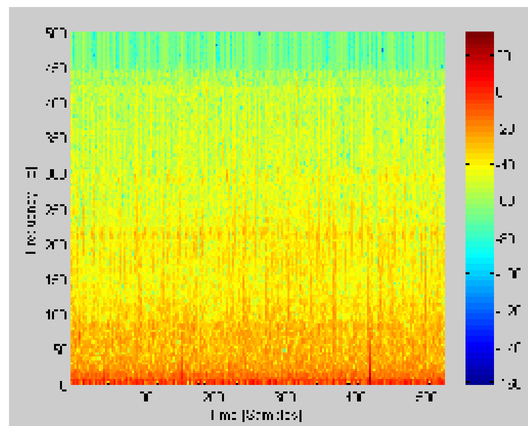

Fig.9 *STFT Spectrogram of the noise generated by main engine and diesel generators 3m from the ship*

Other useful information about the seawater we achieved from the CTD onboard:

Table 1

No.	Depths	Temperature	Salinity (ppt)
1.	0.992	15.0000	15.8886
6.	14.996	12.0906	17.8327
10.	30.216	8.4682	17.9958
14.	45.432	7.2528	18.1169
15.	49.692	6.8922	18.0965

The second point of interest was named PO04 on the map and its coordinates are $44^o 34'_6 N$, $29^o 14'_6 E$; depth 30 m, sea state 1-2, wave hight 1m, air temperature 23^o, wind speed 4 m/s. We made recordings with the hydrophones deployed from the boat which was at a distance of 1.5 nautical miles from the ship. The depths of the hydrophones are 8m, 17m and 25m respectively.

The only equipment working at the ship was a diesel generator.

The results are shown below.

From the spectrogram obtained we can easily notice that all the peaks are under 90dB, but for the one from 100Hz which has 104dB.

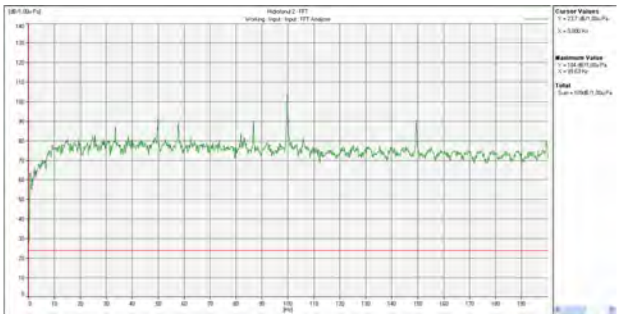

Fig.10 *FFT Spectrum of the noise generated by diesel generators 1.5 Nm away from the ship's hull*

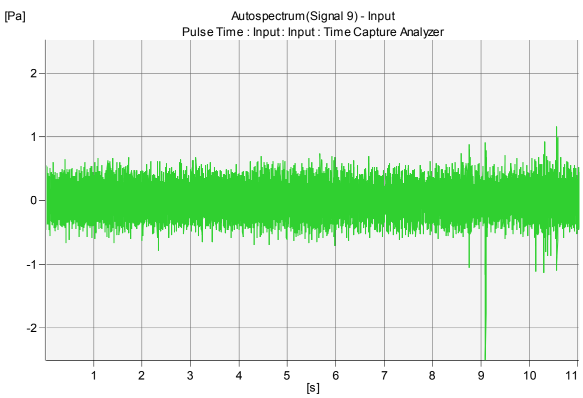

Fig.11 *Underwater noise generated by diesel generators 1.5 Nm away from the ship's hull*

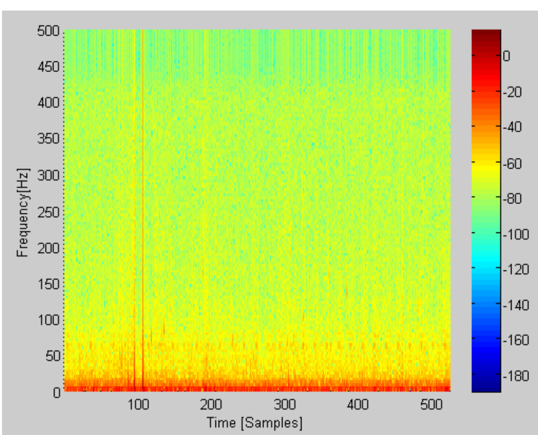

Fig.12 *STFT Spectrogram of the noise generated by diesel generators 1.5 Nm away from the ship's hull*

Back onboard of the ship measurements were taken during stopping the engines. Figs.13,14,15 represent FFT, STFT, DWT of the signal captured immediately during the engines stop; diesel generators and other machineries are working.

Below this we have the spectrogram at one hour after the engines were stopped; in this case only the diesel generators were functional.

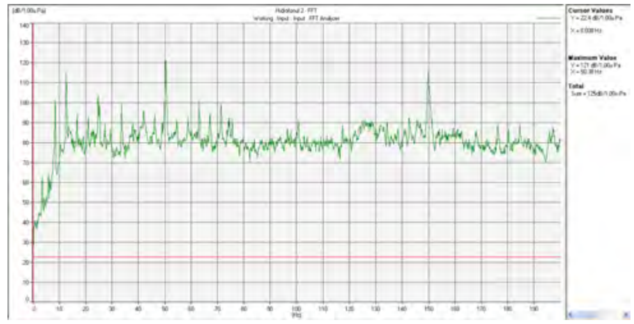

Fig.13 *FFT Spectrum of the noise generated at 3m away from the ship at the engine stop*

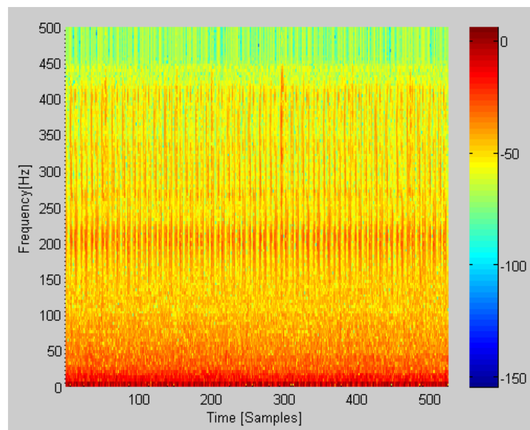

Fig.14 *STFT Spectrogram of the noise generated at 3m away from the ship at the engine stop*

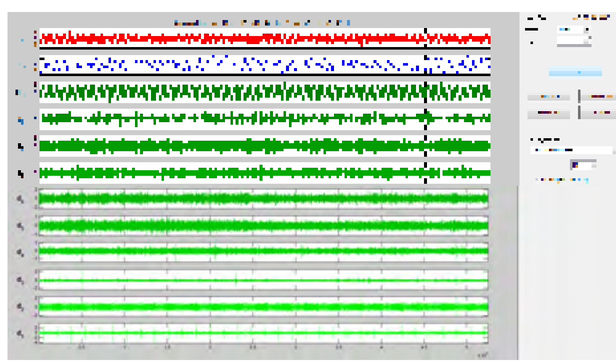

Fig.15 *DWT of the noise generated at 3m away from the ship at the engine stop*

For this area we some other useful information from the CTD:

Table 2

No.	Depths	Temperature	Salinity (ppt)
1.	0.991	10.0217	17.3795
2.	8.298	7.9899	17.8533

3.	16.822	7.3002	18.0595
4.	25.344	6.1557	18.0602
5.	25.953	6.1520	18.0549

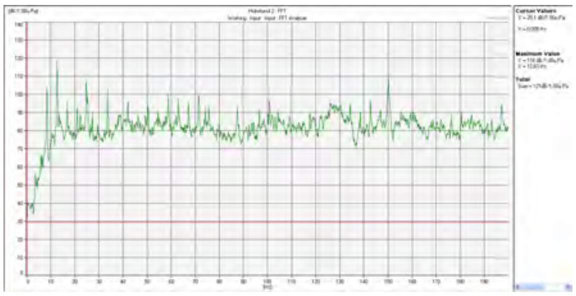

Fig.16 *FFT Spectrum of the noise generated at 3m away from the ship with generator working*

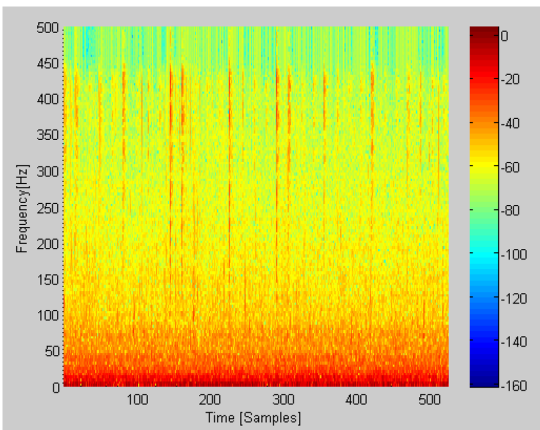

Fig.17 *STTF Spectrogram of the noise generated at 3m away from the ship with generator working*

4 Discussion

Short Time Fourier Transform time-frequency analysis gives us qualitative information on the signals recorded in the Black Sea in the case of working generator or generator and main engine also.

The achieved results enrich the data base over signal's shape and the determination of the time domain complementary numerical parameters.

This processing method is useful in identification of the shape signals which occur during ship operation. Furthermore, the spectrogram shapes calculated in the time-frequency domain are affected by the measurement equipment's power supply.

The spectrograms showed in Figs.6, 9, 14, 17 confirm the frequency changes for the simultaneous operation of diesel generator and main engine, and the amplitudes changes of the new frequency components either.

Furthermore, one can notice emerge periodicity and that the spectrograms show a higher participation of low frequency components which have narrow band behaviour.

From the spectrogram in fig.6 for the start of the main engine it can be observed a constant energy concentration in the bandwidth of frequency 0-50Hz, whereas for at a width band of 0-400Hz it can be notice that the energy has a smaller intensities dispersed at 1-2 seconds.

When the generator is working, small energy concentration can be observed at the frequency band of 0-100Hz and dispersed constant energy intensity at 200 Hz, with small values either (see fig.17).

At very big distances from the noise source (the ship is at 1.5 Nm from the point of measurement), it can be seen that the energy intensity decreases, the maximum values been noticed at the 0-50Hz (see fig.12).

From the DWT analysis (fig.7 and 15) we can state that the energy is bigger at the engine stop than at start, and time distribution is very different.

5 Acknowledgements

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