SIRAMIS : PRELIMINARY ANALYSIS OF ACOUSTIC AND SEISMIC SHIP SIGNATURES

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Abstract: *SIRAMIS is a project coordinated by the European Defence Agency standing for Signature Response Analysis on Multi Influence Sensors. As most of the international trade is carried out through marine routes, it is important to evaluate the vulnerability of the merchant vessel fleet to sea mines in order to be able to limit the potential exposure to this threat.*

In this project, the participating nations pool their measurement and analysis capabilities to improve their knowledge on the underwater signatures of merchant vessels and understanding of the near field ship signature in relevant and realistic scenarios.

The project involves a series of recording campaigns performed near shipping lanes in the national waters of the participants, using various multi-influence measurement systems. The data analysis will help to separate the effect of the differences between the measurement systems and the environments from the features specific to the measured ships. A further analysis will investigate the relationship between the merchant vessels signatures and their characteristics.

This paper presents the initial results of the acoustic and seismic signature analysis.

Keywords: *Merchant vessels, acoustic signature, seismic signature.*

1. INTRODUCTION

SIRAMIS is a project coordinated by the European Defence Agency standing for Signature Response Analysis on Multi Influence Sensors. As most of the international trade is carried out through marine routes, it is important to evaluate the vulnerability of the merchant vessel fleet to sea mines in order to be able to limit the potential exposure to this threat.

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This papers presents an overview of the collected data and preliminary results of the analysis of acoustic and seismic data.

2. OVERVIEW OF COLLECTED DATA

Opportunistic measurements of merchant vessels data were collected using measurement systems from the various participating nations deployed in shipping lanes. The location of the measurements campaigns are presented in the Fig.1. The data from Automatic Identification System (AIS), whose use is mandatory on large vessels, were also recorded. The AIS data includes information on the vessels, such as the length and gross tonnage and information on its trajectory based on their on-board global position system (GPS) receiver. The latter enables to determine the vessels passing in the vicinity of the sensors, as well as their distance to the hydrophone at the Closest Point of Approach (CPA). These opportunistic measurements enabled the collection of large amount of acoustic, seismic, hydrostatic, electric, and magnetic data for a variety of types of merchant vessels, representative of the merchant vessel fleet sailing the European waters: cargo, roro, tankers, ferries, fishing boats, tugs…

In addition to the opportunistic measurements, some specific measurements were using controlled ships and controlled sources as well as measurements with the various mobile systems at the same locations. These measurements enable comparison of the measurements systems, of the environments they are deployed in and of the variability from run to run as well as the influence of the distance at CPA.

Fig.1: Location of the measurement campaigns.

3. ACOUSTIC SIGNATURE AND ACOUSTIC INDICATORS

In addition to the information related to the vessel being measured, the acoustic signal recorded by a measurement system contains information related to the propagation from the vessel to the sensor and on the ambient noise at the time of measurement. Consequently, the acoustic signal can hardly be considered to be the *acoustic signature* of the vessel.

Various mechanisms contribute to the acoustic radiation of ships [1], among which propeller cavitation is often dominating. Other contributions are due to machinery noise and flow noise. All these mechanisms lead to the generation of narrow band and broadband components, whose level and directionality varies with the speed and the mode of operation of the vessel, and, of course, from ship to ship. The received signal results from the propagation of these components and varies with the propagation distance, thereby presenting different characteristics in the far field and in near field. All these aspects relate to the “acoustic signature”, which is not a well-defined concept.

Comparison of the acoustic signature of ships requires the evaluation definition of quantitative indicators that enable such comparison. In order to perform such comparison, the analysis team of the SIRAMIS defined a number of indicators based on the narrow band spectrum and One Third Octave (OTO) spectrum. The selected indicators do not cover the full scope of the acoustic signature, but they enable quantitative measurements and comparison. One of these indicators is the Radiated Noise Level (RNL), which is obtained from the temporal maximum of the OTO spectrum after a correction for the measurement distance [2]:

$$RNL(f) = \max_t OTO(f,t) + 20\log_{10}(r_{CPA}/r_0) \tag{1}$$

Where $OTO(f,t)$ is the OTO spectrum computed as a function of time t and f frequency and the other term is the correction for the measurement distance. The latter assumes only spherical spreading loss over a distance r_{CPA}, which is the distance at CPA, and r_0 is the reference distance equal to 1 m.

A similar approach is adopted regarding analysis of the seismic signals, measured by sea floor mounted accelerometers. However, since the amount of scientific data available regarding this topic is limited, the correction for measurement distance, which is subject to debate regarding the acoustic signature [3], is not applied to the seismic analysis.

4. SELECTED RESULTS

4.1 Variability from run to run

Some of the controlled measurements included several runs of the same ship at the same speed over a measurement system. Fig. 2a presents the maximum of the OTO spectrum recorded for four measurements of the same ship, with varying horizontal offset at CPA, all less than 25 m. This figure illustrates the repeatability of such a measurement, which is of importance when comparing measurements of different ships. Observed differences between ships are significant only providing they exceed this repeatability. It is seen that the overall shape of the measured spectra is fairly independent of the measurement, with a spread mostly below 5 dB at frequencies above 10 Hz.

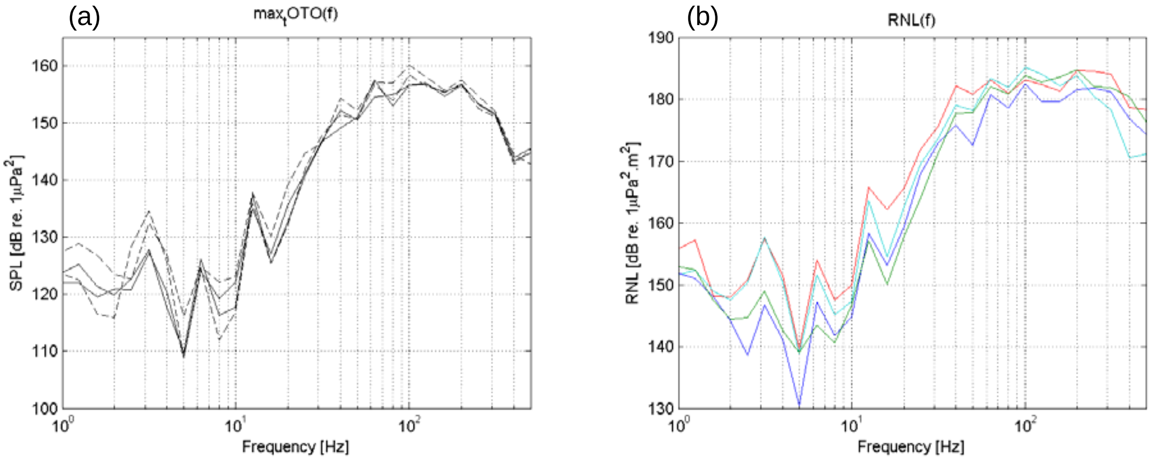

Fig.2: (a)Variability from run to run (repeatability): same ship over at the same location; (b) variability of the environment: same ship at different locations.

4.2 Variability due to the environment

In one measurement campaign, four measurement stations equipped with the same sensors were deployed at separate locations within about 200 m from each other. The water depth at each measurement stations is different. Since the same ships were measured at these measurement stations, this enables to gain some insight on the variability of the measurement due to a change in the environment. Note however that larger differences can be expected when the measurement campaigns are performed in truly separate locations, with different sediment properties.

Fig. 2b shows measurements performed with the same ship at the same nominal speed. Each curve corresponds to a different measurement station and is the average of measurements with horizontal CPA distance below 25 m. The received levels were converted into RNL using formula (1). The spread between the curves is mostly below 10 dB at frequencies above 10 Hz, of the same order as the run to run repeatability.

4.3 Effect of speed and propulsion type

Fig. 3 illustrates the influence of ship operation on the RNL. In Fig. 3a, the RNL of a ship at two different speeds is presented. Both curves are obtained as the average of several runs with horizontal CPA distance below 25 m. In this example, the higher speed causes an increased RNL in most frequency bands, sometimes of up to 20 dB.

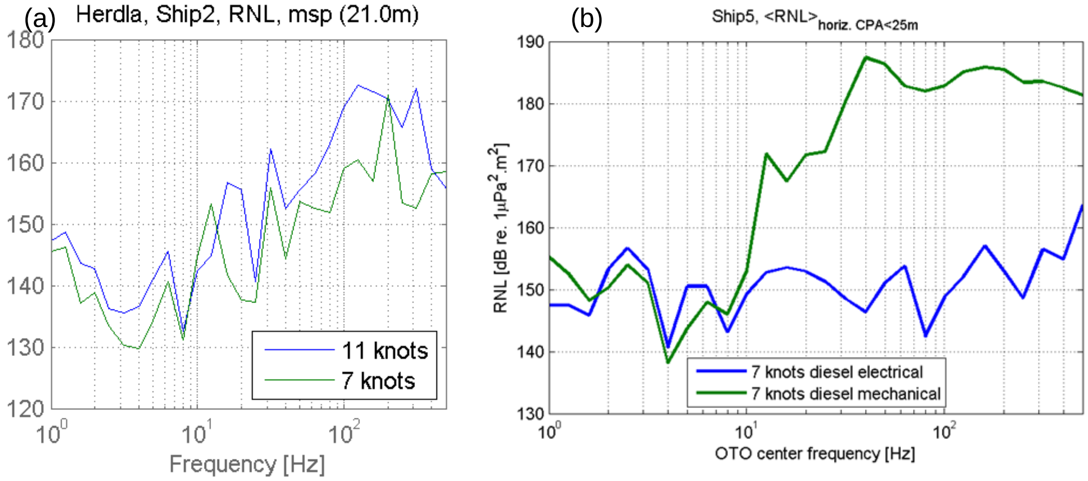

Fig.3: Variability due to speed and propulsion type: (a) same ship at different speeds, (b) same ship with different modes of engine operation.

Fig. 3b is also obtained from an average of runs with horizontal CPA distance below 25 m. It corresponds to a ship sailing at 7 knots whose engine can operate in two distinct modes: diesel electrical and diesel mechanical. In the diesel mechanical mode, the torque from the diesel engine is used to rotate the propeller; in the diesel electrical mode, the torque is used to generate electricity, which is used (possibly among other things) to power an electrical motor that operates the propeller. The latter mode is significantly more quiet than the diesel mechanical mode: the difference is between 20 and 35 dB for frequency bands over 10 Hz.

4.4 Seismic signal / effect of propulsion type

Fig. 4a presents the maximum of the OTO spectrum of the seismic signal for the same ship as in Fig. 3b. The X-, Y- and Z-components corresponds to motion in the track direction, perpendicular to the track direction and in the vertical direction, respectively. They present a similar level within 10 dB. The shape of the OTO spectra is similar to that of the acoustic signal; the difference may be attributed to the frequency response of the seismic sensor. The variation between the two modes of operation is of similar amplitude as for the acoustic signal. Both observations support the idea that the seismic and acoustic signatures are due to the same physical mechanisms on the ship. Fig. 4b presents the narrow band spectrum of the X-component. It indicates that, although the OTO spectra present similar shapes in the two modes of propulsion, the frequency content is dominated by tonals in the diesel electrical mode whereas broadband components dominate in the diesel mechanical mode.

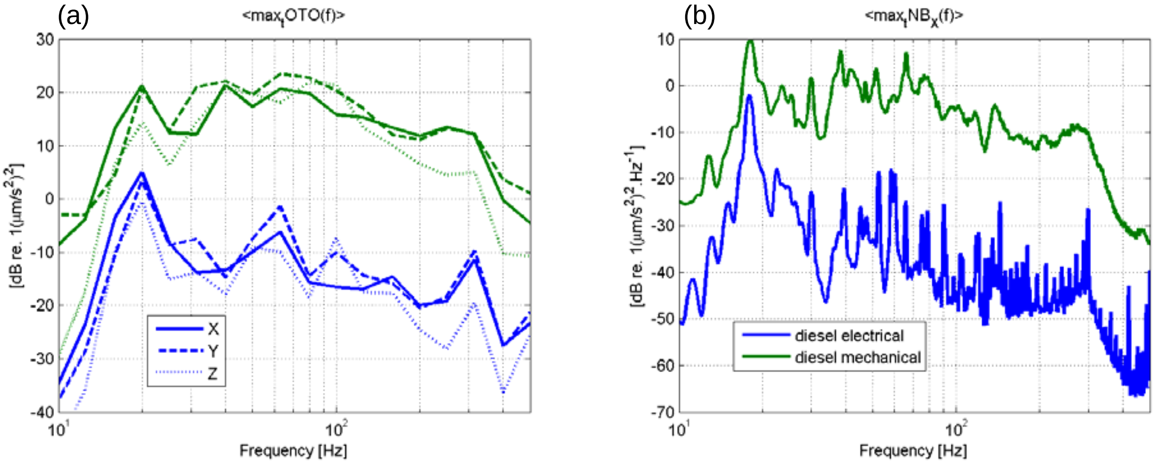

Fig.4: Effect of propulsion type on the seismic signal shown as an OTO spectrum for each component (a) and as a narrow band spectrum for the X-component (b).

5. CONCLUSION

The preliminary analysis of the SIRAMIS data demonstrated a run to run variability of the order of 5 dB and a variability due to the environment that is somewhat larger, up to 10 dB. Significant differences in RNL, i.e. much larger than the measurement variability were observed when changing the speed or the mode of operation of ships. The analysis of the seismic data supports the acoustic observations and indicates that both signatures are related to the same physical mechanisms. Further analysis of the data will be devoted to finding grouping and scaling relationships to model the ship signature as a function of ship type and parameters as in [4]-[6].

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