ANALYSIS OF DIFFERENCES IN THE UNDERWATER RADIATED NOISE OF SHIPS IN THE PORT APPROACH ZONE

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This paper presents the study of underwater noise generated by moving ships associated with the vibration measurements and analysis inside the hull. Two particular areas of noise generated by moving ships in the environment are shipping lanes and approaches to ports. From 2012 to 2015 the Polish Naval Academy in Gdynia participated in a study of ship noise as a participant in the European Defence Agency project SIRAMIS. The study focused on the signature response analysis on multi-influence sensors. During the sea trials, over sixty vessels were measured, and the data analysis found that significant differences exist not only between different classes of vessels but also per vessel. To explain these differences, measurements of vibrations inside a ship's hulls were made. The tests took place on one ship that sailed to Gdynia’s port many times. The results of comparing the underwater noise of the ship with the vibrations of the mechanisms and the hull plating are presented in this article.

Keywords: underwater noise, ship noise, ship vibration, noise measurement, ship’s signature

Introduction

During the measurement campaign of the EDA SIRMIS project, implemented between 2012 and 2015, PNA recorded underwater noise of over sixty ships. The measurement campaign focused on the underwater acoustic signature response analysis on multi-influence sensors. The measurement campaign was conducted in the spring and summer of 2013 near the port of Gdynia in the Gulf of Gdansk. Measurement modules were positioned exactly on the axes of the leading lights indicating safe passage for vessels entering the port of Gdynia.

Over the following years, the measurement data was analyzed. During the analysis, attention was drawn to the large spread of Radiated Noise Level (RNL) of ships of the same class, but also of the same ships making repeated calls and departing from the port of Gdynia. A scaling method was used to calculate the resulting radiated noise level (RNL) from the Sound Pressure Level (SPL) measured at a distance of r as:

\[ RNL = SPL(r) + 20 \log_{10} \left( \frac{r}{1\,m} \right) \]  \hspace{1cm} (1)

where \( r \) = the distance between the hull of the measured ship and the sensor laying on the sea bottom.

The purpose of measuring such a large number of ships was to estimate the repeatability of underwater noise measurements generated by selected classes of ships near the port. The results of the research [1, 2] were presented at the Seventh Forum Acusticum 2014 (FA 2014) in Krakow and at the Twenty-First International Congress on Sound and Vibration 2014 (ICSV 21) in Melbourne. The article presented at ICSV 21 served as a development of the issues presented at FA 2014. After the presentation at FA 2014, the reactions were very positive. Professor Leif Bjorno stressed that based on his own experience, he could confirm that in the case of a shallow sea and heavy traffic waterbody, differences in RNL could reach up to 20 dB. De Jong et al. reported that the maximum observed RNL in keel aspect
in a given environment which is reported as output of the NATO AMP-15 procedure could differ by more than +/- 10 dB (in 1/3-octave bands) from the acoustic source level that is required as input for most acoustic propagation models [3]. In some publication [4-8] have written that in coastal regions (shallow water), the contribution of ship noise may also dominate the low frequencies but is more difficult to predict because of the variability in ship noise in coastal regions relating to the proximity to shipping lanes and local sound propagation conditions. By contrast, the article presented at ICSV 21 received much criticism such as doubts about whether, the appropriate Closest Point of Approach (CPA) was known, if the ships had been mistaken, or if the sensors had been properly calibrated before the measurement. Trend lines characterizing the RNL spread reaching 8 dB did not make sense (Fig. 1). Figure 2 shows a histogram of ship speed, which shows that ships left the port with the same speed (4 from 5 runs).

Figure 1: Characteristic of RLN versus speed of investigated passenger ship.

Figure 2: Histogram of ship speed.
All the time, research related to the parameterization of the underwater noise of the ship as well as the on line monitoring of the hull vibrations and internal mechanisms are ongoing [9] [10].

Since they were opportunity ships, during the recording of underwater noise no measurements of vibrations inside the ships’ hulls were made simultaneously. The position of the measurement modules at the bottom of the sea was determined by the GPS receiver and the position of the ship by the AIS signal. In the case of some ships, after entering the port, the parameters of the ships’ movement derived from the machine log. These critical remarks became the reason for the further research described in this article. A similar dispersion of the RNL parameter was characteristic of all ships moving through this waterbody. A ship was selected that entered the port in Gdynia on a daily basis, allowed onboard access, and shared technical documentation containing ship movement parameters in hydroacoustic field measurements.

Description of the research object

As a research object, a ferry ship was selected which sailed everyday on the cruising line: Gdynia – Karlskrona – Gdynia.

The most important parameters of the investigated ship are hereinafter described:

1. Length/Beam – 176m /30m.
2. Draught – 6.6m.
5. AIS Type: Passenger ship (HAZ-A).
6. Main engines: 4 × Sulzer 16ZV 40/48 Sulzer/Zgoda, 29 400 kW.
7. Auxiliary engines: 5 × generating sets, 5 000 kW.

The ship selected for research was characterized by a considerable complexity of the propulsion system and the Auxiliary Power Units (APU). Commercial vessels usually have one propeller whereas passenger ships (e.g., ferries) have two propellers. For safety reasons, the ferry takes 1,700 passengers, a crew of 100, and can take up to 500 different kind of cars, buses and lorries. The ferry has 4 main engines, 5 auxiliary engines (APU), two variable pitch propellers and two bowthrusters.

The arrangement of the ship's engines and propellers is presented in Fig. below:

![Arrangement of ship's engines and propellers](image)
Investigation of the ship and results

In June 2015, vibration measurements of a passenger ship sailing daily from Gdynia to Karlskrona were carried out. The measurement team was recording the vibrations and noise inside the engine room for two days. At that time, the selected ship left the port in Gdynia twice, twice arrived at the port of Karlskrona, left it twice and arrived twice at the port of Gdynia. During the tests, vibration measurements were taken in the ship's engine room from the start of engines to the moment of going out to sea for 15 minutes, before entering the port, 15 minutes before stopping the engines and for 15 minutes while the ship's engine parameters were constant. The first stage of the research was the Log Engine Room analysis in terms of main and auxiliary engines operating during the acoustic field testing of the ship. Table 1 presents the results of the analysis.

Table 1: Configuration of ship's engines for selected points

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<th>RNL [dB re 1μPa²m⁻²]</th>
<th>Speed of ship [m/s]</th>
<th>ME1</th>
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ME – Main Engine,
AE – Auxiliary Engine.

The results show that an arrangement of the driven systems is very variable. During measurements when two to four main engines were working, as well as one to four auxiliary engines, the pitch of the propellers was variable – different pitches in different runs and different pitches on each working ME. The mechanical crew claimed that not every turned on device was immediately recorded in the machine log, e.g. the turning on of bowthrusters was recorded after the fact, and their work depended on the short-term need for changing the course of the ship, and their preparation for work included turning on the AEs.

The second phase of investigation covered the measurement of vibration of the main engine’s 1L foundation and noise measurement of the whole Engine Room during entry to the harbor, leaving the harbor and during cruise with a constant speed and constant parameters of the machines. Because the main engine was a V engine, accelerometers in different points of the foundation were placed in a vertical direction.

Firstly, the FFT analyses were made in order to determine the frequency ranges used by the engines and other devices onboard. Since the ship was equipped with low-speed main engines and medium speed auxiliary engines, it was expected that the Power Spectral Density analysis would indicate that most of the vibroacoustic energy would be in the band of low frequencies. Fig. 4 shows the average effective velocity of main engine vibration. The FFT graph was averaged during 72s.

These characteristics accurately present the dispersion of vibration in the analyzed frequency range (0 – 1 kHz).

It can be observed that the lowest significant frequencies are 6.25 Hz and 12.5 Hz. These values are variable depending on the main engine speed. The speed of the auxiliary engine, 750 RPM, is constant.
because of electrical power generation with a frequency of 50 Hz. Above a frequency of 600 Hz, the range of generated energy is much lower than the 0 – 600 Hz frequency band. Characteristics of average effective velocity $V_{RMS}$ versus time are presented in Fig. 5, where $V_{RMS}$ characteristics for two different frequency bands – color black: vertical direction, $V_{RMS} (dt = 1s)$, $\Delta f = 10$ Hz – 1 kHz, color green: vertical direction, $V_{RMS} (dt = 1s)$, $\Delta f = 600$ Hz – 1 kHz.

![Figure 4: The FFT analysis of velocity of vibration.](image)

![Figure 5: Comparison of $V_{RMS}$ of vibration in two different frequencies bands: color black: $\Delta f = 10$ Hz – 1 kHz, color green: $\Delta f = 600$ Hz – 1 kHz.](image)
Fig. 5 presents the $V_{RMS}$ of vibration in two different frequency bands at the time of the entrance to the port of Gdynia (2 ME: 1L, 1R + 3 AE). An approximate 6-fold difference between frequency bands can be observed, which means that most of the generated energy is concentrated in the 10 – 600 Hz band. An analysis was carried out in the 10 – 1000 Hz frequency range due to the standard [4] applied at the time. It should be emphasized that the large spread during the black run as well as differences in values between black and green lines after the ship’s engines stopped is a result of typical noises on the ship (turning on the car engines, passengers leaving the cabins, waves hitting the hull, and the hull was based on fenders). Interestingly, this is visible only in the 10 – 600 Hz frequency band. Fig. 6. shows the spectrogram of the characteristics presented in Fig. 5. On this spectrogram it is seen that not only does the $V_{RMS}$ value of vibration change, but also the frequencies (machines speed).

However, due to the fact that in Fig. 4. significant harmonics below 10 Hz are also visible, it was decided to perform an analysis in the 3 Hz – 1 kHz frequency band. When the ship was constant course and speed of the ship, there were no significant changes in the frequency of the working engines and other ship equipment.

![Spectrogram](image)

**Figure 6:** The spectrogram of characteristics presented in Fig. 5.

Fig. 7. presents the $V_{RMS}$ characteristics measured when the investigated ship left the harbour (3 x main engines were working, 1L, 2R). The black waveform presents the vertical direction of the accelerometer mounted on the main engine: $V_{RMS} (dt = 1s), f = 10$ Hz – 1 kHz, ). The green waveform presents the vertical direction of the accelerometer mounted on the ME: $V_{RMS} (dt = 1s), f = 3$ Hz – 1 kHz. In the presented course, the distance between the minimum and the maximum $V_{RMS}$ values of the course reach twice the minimum value. In addition, it can be observed that the green waveform has a higher $V_{RMS}$ level of about 10% more than the black waveform. This proves that in the frequency range of 3 Hz – 10 Hz there is an average transfer of 10% of the acoustic energy generated by the hull of the ship into the water. Considering the rotation speed range of the main engines, their first harmonic is located there. An observation of the ship’s entries and departures provides the information that each $V_{RMS}$ course is unique, as confirmed by Table 1 and by later carried out vibration measurements of the main engines, where each has a different course. The results of the RNL measurements confirm that
cycles of variable loads of the main engines are not related to any particular geographic position of the ship. Apart from the main and auxiliary engines listed, variable pitch propellers have a significant impact on the energy balance of underwater noise. It was observed that when entering the port, the bolt worked backwards, inhibiting the movement of the ship, which was constantly moving forward, increasing the $V_{RMS}$ level of vibrations, while the rotation speed of the main engines was constant.

![Graph showing vibration characteristics](image)

**Figure 7:** The characteristics presented $V_{RMS}$ of vibration when ship was leaving the harbour: color black: $\Delta f = 10 \text{ Hz} - 1 \text{ kHz}$, color green: $\Delta f = 3 \text{ Hz} - 1 \text{ kHz}$.

**Conclusion**

This article attempts to point out that in certain environmental marine conditions, the area of ports and intersecting zones of traffic separation schemes ships the RNL levels achieve a much larger spread than the levels of the ships which sail a constant course and speed.

An attempt to understand the parameter dispersion during the entrance to the harbor and the departure from the harbor and during the maneuvering led to the conclusion that the dispersion of $RNL$ is mainly caused by a change in the parameters of the engines and ship mechanisms, which is completely normal in changeable navigation conditions (changing the speed of the ship due to obstacles, movement of other vessels, and avoiding collisions). The human factor should also be taken into consideration. The crew needs to ensure the safety of sailing. Summing up, it can be said that each captain (the captain of the ship) has their own style of command and depending on the assumed safety margin, they will start more or fewer main and auxiliary engines to implement the old principle of behavior at sea: Safety First!

These studies show that the characteristic of the presented conditions of underwater vessel noise measurement is the spread of $RNL$ parameters (and other parameters like dominant frequencies in the
spectrum). Whereas, for the presented results, environmental conditions (e.g. type of sea bottom) and hydrometricological factors are of lesser importance, since all measures were carried out in the same place, using the same measurement set under very good measurement conditions: sea state 0 – 2, wind force 0 – 3 °B, no stream, no tide and no precipitation.

During the presented measurement campaign, the hydroacoustic team of the Polish Naval Academy measured more than 60 vessels, which sailed above measurement modules 145 times (runs). The obtained results are very similar to the selected passenger ship presented in this article and confirm the universality of the obtained results. In addition, it is worth mentioning that the area of approach to the port and anchorage is of strategic importance for the whole port, hence there is a need to monitor the underwater noise of ships due to the tasks of mine counter measure (MCM) and harbor protection.

The works will be continued in order to develop a method for calculating average parameters for each ship moving in the described area. It will allow you to set up appropriate RNL levels to develop noise maps and forecasts for a given water area.

REFERENCES