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UNDERWATER SHIP NOISE

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The underwater ship noise is a subject of interest from a few points of view. Two of them are worth to mention. The first one is the fact that both the merchant and military shipping constitutes a major source of noise in the sea. The second one is the important application of underwater noise features in the underwater warfare. The paper presents some summarized knowledge on the underwater sound generated by ships.

INTRODUCTION

The interest in underwater sound generated by ships has a reach history. It begins from the World War II. The results of investigations of that period were described in a textbook by Urick [4]. Many European researchers in Germany, Norway, Sweden, Finland and Poland have contributed to ship noise and propeller investigation. Also it is worth to mention the textbook of Donald Ross where he summarized results of his study on noise of commertial ships and trends in ship powering.

A lot of older results of measurements were obtained with third-octave bandwidth analysis, which is too wide for separation of the individual features of radiated ship noise. Furthermore the data were obtained as a result of measurements in the shallow water, so they may not be representative of free-field values, taking into account the above mention facts and also high cost of ship time and measurement facilities and military application of data it is not surprising that detailed results of measurements of ship are difficult to available.

1. CHARACTERISTICS OF UNDERWATER NOISE RADIATED BY THE SHIP

The main sources of the ship noise are as follow:

- ship's service diesel generator,
- propulsion engine,
- ship propeller.

At the low ship speeds the ship's service generator is the main source of the underwater noise generated by ship. It radiates tonal components that contribute almost all of the radiated noise power of the ship. They are independent of ship speed. Few of components are enough strong to be contributors to high-speed signature. The tonal levels of ship's service diesel generator are nearly stable in amplitude and frequency. The wide-band energy of the noise generated by ship's service generator is proportional to the square of generated power.

2. PROPULSION ENGINE

The propulsion engine is a main source of underwater noise for moderate speed of ship. The tonal components are connected with firing rate. For the two-stroke x-cylinder diesel engine the firing rate is defined as:

$$\text{Firing rate (FR)} = \frac{x \cdot rpm}{60} \tag{1}$$

where x- number of cylinders.

The tonal level is not stable in general because of variations of loading as is propeller for different sea state. The radiated power at the fundamental firing rate frequency F is related to engine horsepower H as:

$$W \sim (H \cdot F)^2 \tag{2}$$

and can be estimated up to 0.1% of the total engine power.

Analizing the vibration engine caused by diesel engine that is converted into acoustic energy one should take into account the possibility occuring structural resonances these may play a great role in determining the radiation efficency of the ship's engine tones.

3. PROPELLER NOISE

The most efficent underwater noise source on the ship is the propeller noise. One part of it is so called blade rate, that is a signal at the blade passing frequency and its harmonics. This gives usually the dominant contribution to low frequency tonal level at high speeds of ship, when the propeller is heavily cavitating. The relation that inform us about the possibility of occuring the cavitation is the cavitation index as:

$$K_t = \frac{p_0 - p_v}{\frac{1}{2}\rho V_0^2} \tag{3}$$

where p_0 - ambient pressure at the tip depth,

p_v - the water wapour pressure,

ρ - water density,

V_0 - propeller tip velocity relative to the surrounding water.

Because the work of propeller is near the hull, the inflow velocity is reduced significantly near the top of the propeller. A surface ship propeller operates behind the hull which creates a nonuniform wake inflow velocity and variation of the sea surface due to wind causes that the upper region of the propeller blades motion is the lowest pressure as usually. For the high rotation speed a cavity can be formed that collapses when the pressure increases during the blade downward. Because the collapse of a cavity occures every time a blade passes through the region of low pressure, noise has fundamental harmonic equals the blade rate, and its harmonics.

Estimation of the sound pressure generated by cavitating area can be done by assuming that the pulsation of cavity may be approximated by a monopole source. Because the process take place in the vicinity of the free-pressure surface so the nearly perfect reflections of the sound waves occure as the second source. In result of them the radiation pattern of the propeller noise has a dipole character with a dipole directivity pattern.

The simple expression described the dipole pressure is as follow:

$$P_d(t) = \frac{4\Pi fd}{c} P(t) = \frac{d\rho}{2\Pi rc} \frac{d^3V(t)}{dt^3} \qquad (4)$$

where r - distance from the source,

f - frequency,

d - source depth,

c - speed of sound,

V(t) - instantanous cavity volume,

P(t) - acoustic pressure.

4. MEASUREMENT FACILITY

The best location of the measurement facility is that where the ambient noise is the smallest and the depth of sea is enough high that the bottom is reflectionless one. The best location of hydrophones array for this purpose is a bottom-mounted set-up. The good hydrophone array has 3D form because this allows to determine the complex acoustic directivity pattern of noise radiated by the ship. The runs are recorded by means of multichannel tape recorder. The resulting data as the spectra are used to provide an input to special directivity analysis procedure that allows to obtain the directivity plots.

At the same time on-board measurement of the main engine and the service diesel generator vibration are carried out. On the base of result of this measurements one can determine the noise bandwidth from the ship, diesel engine cylinder pressure spectra, engine vibration transmission paths, ship hull "beam mode" response and at last the transfer function between the on-board instalated sources of vibration and outside radiation level.

Some measurements carried out during the investigation of the ship noise are illustrated below.

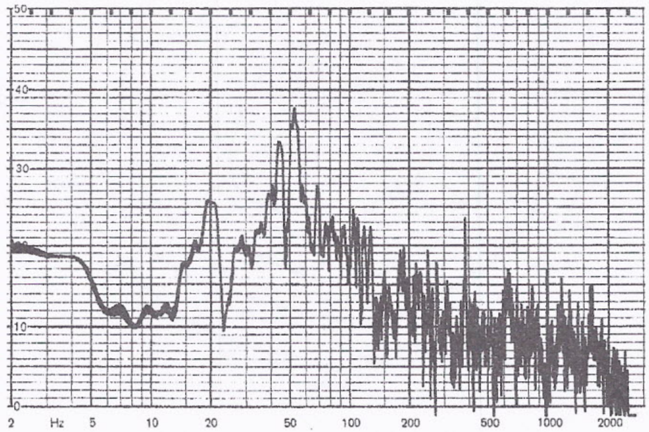

Fig. 1. The typical form of narrowband spectrum of the ship noise

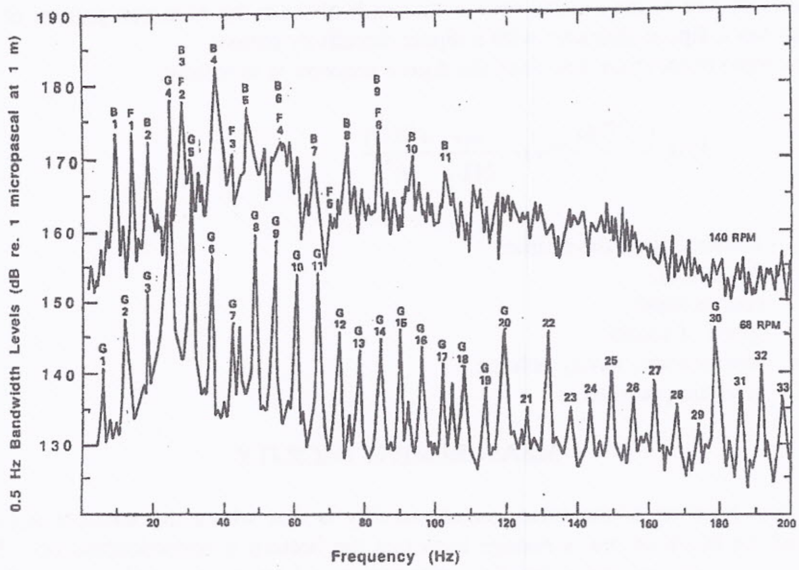

Fig. 2. Keel-aspect narrowband spectra in 0.5 Hz bands at low (65 rpm) and maximum speed (140 rpm) [2] where: G- ship's service diesel generator, F- diesel firing rate, B- blade rate

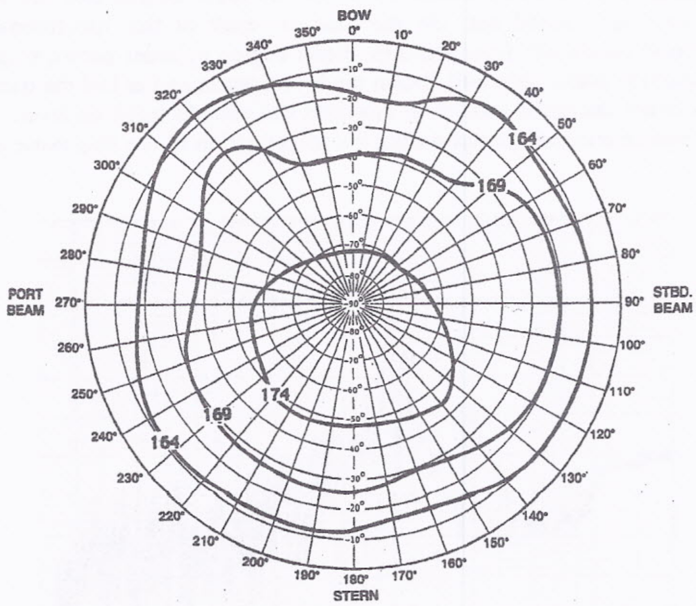

Fig. 3. Directivity pattern of ship noise [2]

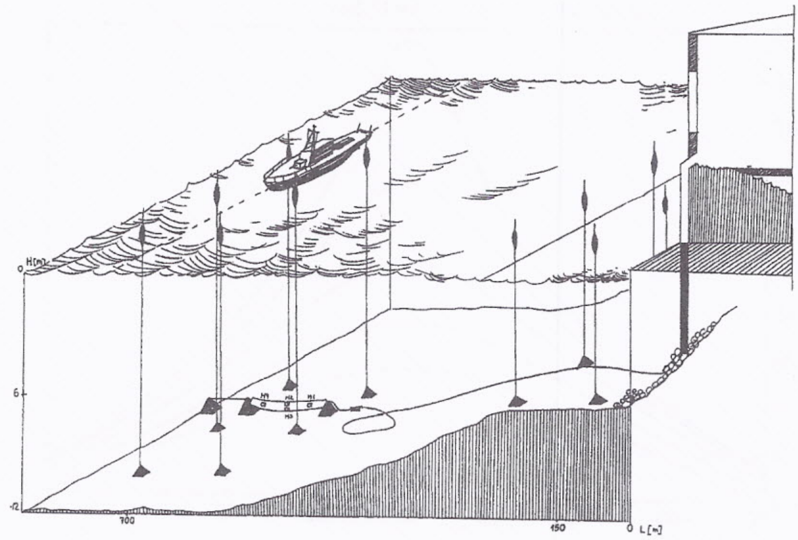

Fig. 4. Configuration ship-measured hydrofon array

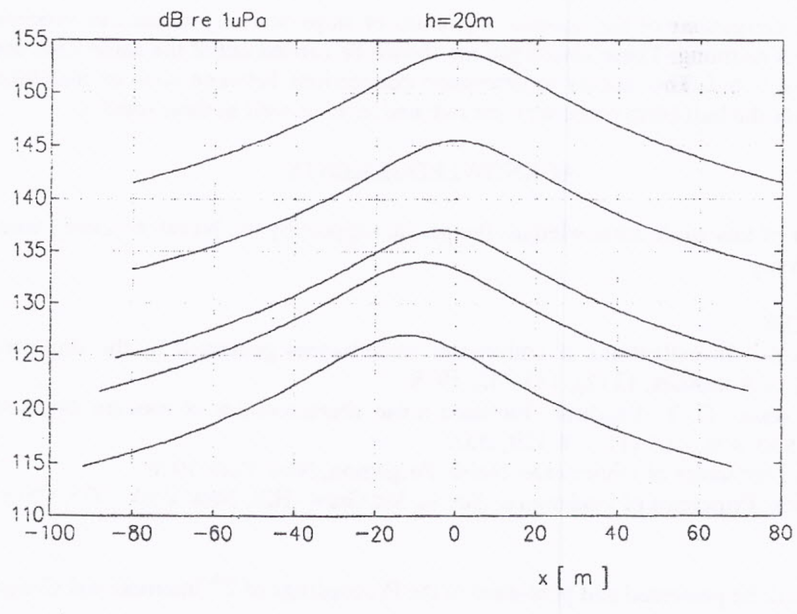

Fig. 5. Sound pressure level as a function of speed of the ship obtained for the 20 cm depth of water

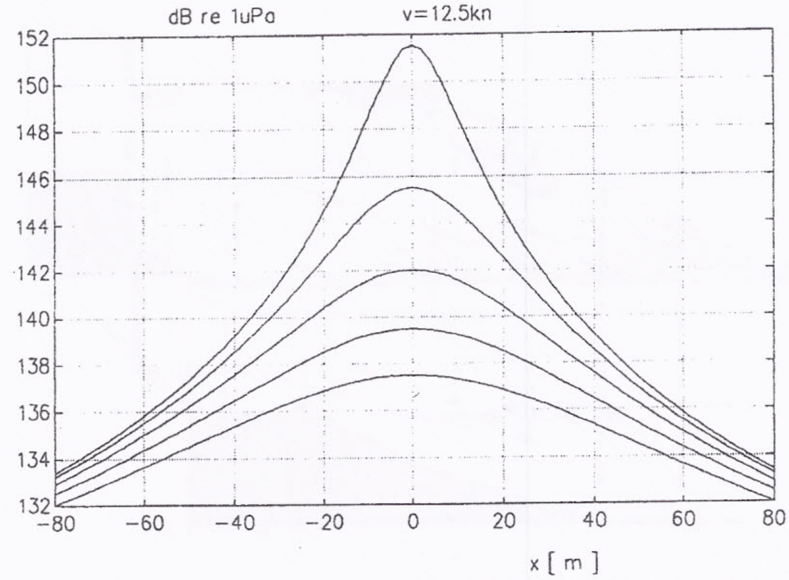

Fig. 6. Sound pressure level as a function of depth for constant forward speed of the ship.

5. SUMMARY

The investigations of the acoustic signature of ships are very expensive procedure as well as time consuming. These investigations should be carried out at the same time both on-board and out-board. This allows to determine connections between sources installated on-board and near the hull (ship propeller) and radiated level as well as their spectra.

ACKNOWLEDGEMENTS

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This paper will be presented and published in the Proceedings of 7th International Congress on Sound and Vibration.