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Propeller cavitation noise and background noise in the sea

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ABSTRACT

Background noise in the sea from commercial shipping has increased over the past decades and affects marine life in a variety of ways, mainly masking of vital communication calls of baleen whales.

The cause of this low frequency noise is solely attributable to propeller cavitation at frequencies below 300 Hz. The noise spectrum features a characteristic maximum at around 50 Hz with most ships independent of type, size and speed. This spectrum and its cause are widely unexplained.

This paper describes the observations made in full scale ships particularly with respect to the broad band part of the low frequency spectrum. A simple acoustic ship model is presented and procedures to investigate into the physics of noise generation by cavitation are suggested and the possible influence on background noise in the sea be estimated.

1. Introduction

Background noise in the sea caused by anthropogenic sources became of increasing concern due to its possible negative effect on marine life. One of the most recent impressions concerning shipping noise came from the International Maritime Organization IMO in early 2014 (IMO, 2014).

The most pressing problem can be located in the low frequency regime below around 300 Hz (Andrew et al., 2002; McDonald et al., 2006). The background noise spectrum in the deep oceans has some similarity with the radiated noise spectrum of most individual ships. Frequencies below 300 Hz are used in vocalization of large baleen whales. Comparing background noise with and without ships suggests that the range over which the animals could communicate is reduced to a fraction due to the presence of ships. Fig. 1 shows the contribution for Sea state 2 and distant shipping derived from Urik (1983).

The discussion of whether shipping noise has an adverse effect on whales or marine life in general alone or together with other stressors will not be discussed here. Note, that shipping noise contribution has a characteristic shape with a peak at around 50 Hz (Arveson and Vendittis, 2000; Committee on Potential Impacts of Ambient Noise in the Ocean on Marine Mammals, 2003).

In the following it shall be shown that background noise can be attributed to single ships and the low frequency part solely to the cavitating propeller. Measurements of ships at different speeds help to quantify this contribution (Arveson and Vendittis, 2000; Wittekind, 2009). Emphasis is on large ocean going ships with fixed pitch propeller as these are the main sources of continuous low frequency noise from shipping.

2. The noise source and its characteristics

For describing the noise characteristics we make a difference between tonals and broad band noise. Tonals are single frequency signals represented by the spikes in e.g. the diagram in Fig. 3. Broad band noise has the appearance in frequency ranges between the tonals without a stable spectral signature. To the ear this noise appears as a hissing of rumbling sound depending on the frequency range considered.

Six contributors to noise from propellers are identified based on authors' analysis:

1. Noise transferred to the hull from the pure displacement effect of the blades. This will show as multiples of blade rate and is hardly directly observable at distance. The effect comes also with the non-cavitating propeller. The contribution observed in far field are not from direct radiation but likely rather from hull excitation through thrust variations.
2. Tonals at blade rate harmonics caused by cavitation developing during passage of blades through areas with low inflow velocity.
3. A broad band contribution in the frequency range where blade rate harmonics are observed.
4. A broad band contribution at high frequencies caused by cavitation bubble collapse.

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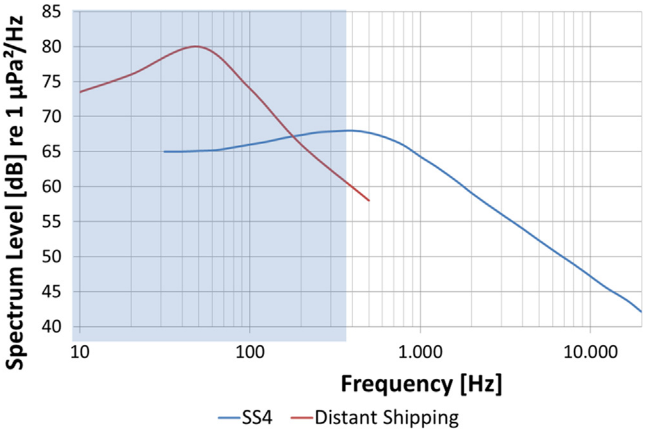

Fig. 1. Background noise in the sea at sea state 4 due to wind and waves and shipping derived from (Urick).

5. Radiation of vibratory response of blades caused by turbulent flow over the blades. In case of the cavitating propeller this contribution is comparatively small.
6. Tonals caused by vortex induced vibrations know as propeller singing. This phenomenon is understood as to only occur in case of the non-cavitating propeller.

In this paper we consider only contribution 3 in connection with 2 covering the tonals and broad band contribution below 300 Hz. While the tonals are understood as the main cause of vibration on board, the broad band part does not harm comfort or is in conflict with other criteria. However, low frequency broad band cavitation can be seen as the primary cause for background noise in the sea as shown below.

The overall appearance of the resulting spectrum of a ship may look like Fig. 2 showing also the relative contribution of machinery. Increasing speed leads to rapidly growing levels at low frequencies with little or no shift in frequencies while the spectrum rises from high frequencies towards low frequencies with increasing speed.

It is this contribution 3, the low frequency broad band part, which will be discussed in more detail.

3. Measurements

Measurements were made onboard Hansa Europe, a 3,600 TEU container vessel during a voyage across the Atlantic. The ship is operated by Leonhardt & Blumberg. Measurements were made by the China Scientific Ship Research Center (CSSRC), Wuxi, China, supervised by one of the authors (Max Schuster).

Vessel characteristics are:

Displacement	63,581 MT
Length between perpendiculars	224 m
Breadth	32.2 m
Summer draft	12.5 m
Engine rating	31,710 kW at 104/min
Speed at 96.5 rpm	22 knots over ground
Power at 96.5 rpm	20,660 kW
Prop area ratio	0.732
Prop mean *P*/*D*	0.936
Prop diameter	7.75 m
Prop skew angle	37.8°
Prop number of blades	5
Prop designer/maker	Mecklenburger Metallguss

Five pressure transducers were mounted in the hull above the propeller in the propeller plane according to ITTC standard (ITTC, 1999). Cavitation was observed via a borescope arranged in another hull penetration.

Pressure variation analysis has been made up to a frequency range of 1200 Hz with a resolution of 0.1 Hz.

Visual observation showed that the propeller develops not unusual sheet cavitation with strong tip vortex cavitation and vortex bursting. Pressure pulses at blade rate come up to 2.6 kPa at approximately 70% delivered power which is an acceptable result for this ship, Fig. 3, i.e. it would not lead to high vibrations on board. Fig. 3 suggests that in the normal display with linear scale on both axes the tonals at the harmonics of blade rate dominate the picture.

4. Evaluation

Evaluation concentrates on the broad band, low frequency part of the spectrum but well beyond the range where blade rate harmonics seem to dominate. Fig. 4 shows the averaged spectra for the highest and lowest speed measured with the third octave conversion for the higher spectrum. Note that the data in Figs. 3 and 4 below 50 Hz is the same for the higher speed. It can be observed:

1. Increasing speed leads to a uniform increase in level both for blade rate tonals and the broad band part in most parts of the spectrum. The increase follows a 80log(velocity) law.

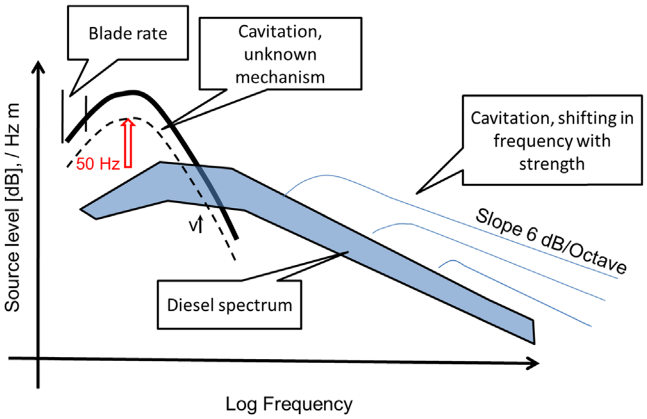

Fig. 2. Generic spectrum of a commercial vessel with effects from speed variations as developed by the authors.

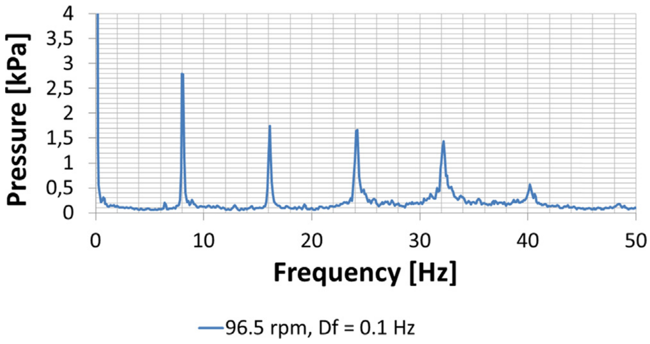

Fig. 3. Pressure pulses measured at the hull shell above the propeller.