Analyzing underwater radiated noise of a 3600 TEU containership

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Introduction

While anthropogenic underwater noise rises on the agenda of environment stakeholders and regulating bodies there is a lack of solid information on the noise generating mechanisms and possible mitigation measures. This concerns in particular the main contribution from commercial shipping.

This paper reports on a comprehensive research program to analyze propeller generated noise of a containership in full scale. Propeller noise was directly measured on board by hydrophones mounted above the propeller. The ship has also been measured during its passage through the English Channel under the same conditions.

Ship and measuring sites

The ship investigated is a 3600 TEU containership built in China and operated by Leonhardt & Blumberg. The ship is well known from model scale tests in China and Germany. It exists with several sister ships with at least two different propeller designs operated also by other companies. The ship investigated here was the HANSA EUROPE using a propeller designed and manufactured by Mecklenburger Metallguss MMG. The parameters of ship and propulsion are:

Length p.p.	223.57 m
Breadth	32.2 m
Max. dead weight	47.381 tons
Design speed	23.2 kts at 104 rpm
Power MCR	31710 kW
Propeller diameter	7750 mm, 5 blades
Draft during measurement	11.52/11.53 m fwd/aft
Speed through water during measurement	14.9 kts/75 rpm 8.5kts/44 rpm

Measurements were made on board during a voyage between Europe and South America in 2010. The ship was measured again in the English Channel at a distance of around 100 m during her voyage to Europe in 2014. The measurement onboard was made by pressure sensors mounted above the propeller directly sensing the pressure pulses of the propeller. At the same time the development of cavitation was visually observed using a borescope.

For the measurement in the Channel a boat was chartered which followed the ship during its passage. Emphasis was made to disturb the ship as little as possible. The ship approached at low speed for a first measurement and then accelerated to higher speed while the boat overtook the vessel. Then a second measurement was made. At both measurements the rpm settings of the propeller were the same as have been selected during the onboard measurements.

Figure 1 shows the ship during one of the measurements. It can be seen that the sea state conditions were quite unfavorable for sensitive measurements but due to the high measured levels they were still undisturbed by environmental contributions.

Figure 1: HANSA EUROPE approaching the measurement site in the Channel

Water depth was 58 m during the first measurement and 64 m at the second. Closest point of approach was around 115 m in both conditions.

Figure 2 shows the conditions in regard to current, wind and waves.

Measurement was made with a single hydrophone with a cable length of 45 m. Due to drift of the boat caused by wind the hydrophone could not be suspended vertically downwards but assumed the geometry depicted in Figure 3. Range was determined via GPS tracks of the vessel and the measuring boat and by laser as backup. Range between ship and hydrophone was then corrected according to Figure 3.

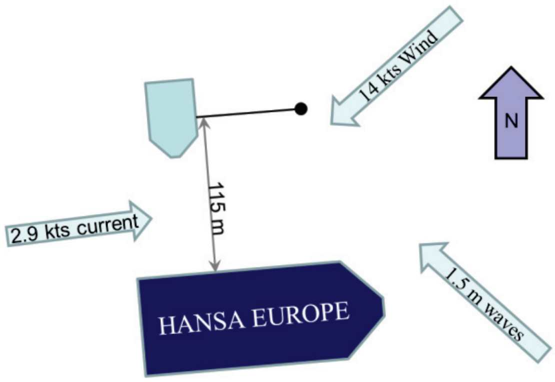

Figure 2: Environmental conditions during the measurements

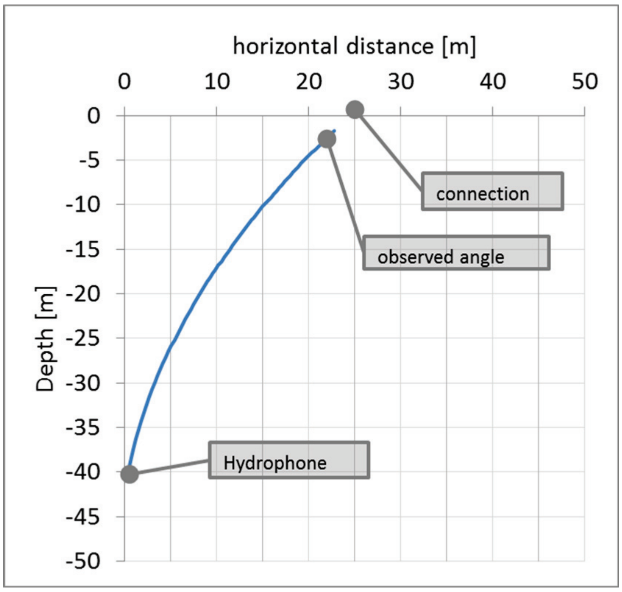

Figure 3: Estimated geometry of the cable during the measurement

The sea bottom consists of hard material with high density and speed of sound and is therefore highly reflective.

Evaluation

Evaluation was made in the following way:

- Reflective properties were assumed such that there is total internal reflection of the bottom
- The geometry of the measurements leads to four propagation paths to be considered, further propagation paths with more bottom reflections lead to deviations which are considered to be within the accuracy of the procedure. The propagation paths were considered by their length and all four contributions are added at the position of the hydrophone maintaining phase relationships. The result is the transmission loss from an assumed point source to the receiving hydrophone (Figure 4)
- The ship is assumed as a point source which is acceptable for the propeller in cavitation. To correctly deal with its contribution the source depth has to be known. We assumed 6 m for the propeller under considerations of the static draft at the time of the measurements and stern wave and trim of the ship
- Machinery is not a point source but was treated as one. Also a 6 m source depth was assumed, which, however, is not so important at higher frequencies

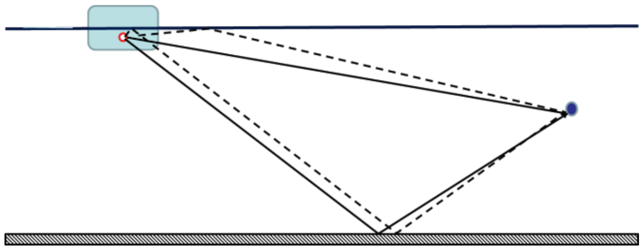

Figure 4: Main propagation paths contributing to the received level

The transmission loss calculated for the geometry as described is shown in Figure 5. The calculation is done in narrow band and then averaged for each third octave. For comparison spherical spreading (TL = 20log(R)) and cylindrical spreading (TL = 10log(R)) is shown. It can be seen that above 60 Hz the transmission loss is about 5 dB lower than spherical where 3 dB could be accounted for due to surface reflection and 2 dB from bottom reflection.

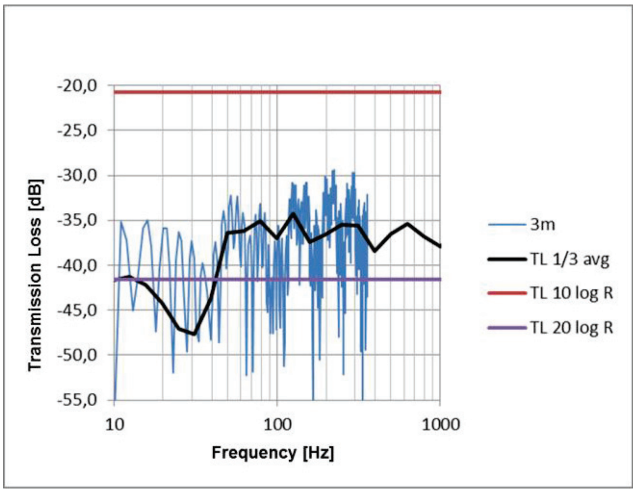

Figure 5: Calculated transmission loss

The levels measured above the propeller during the voyage of 2010 are used to calculate the source level. For this the measured levels were corrected with + 20log(3.5 m/1 m) where 3.5 m is the distance between the hull and the propeller tips.

Both procedures for determining source level will lead to the monopole level which is the level of the ship in an unbounded environment as opposed to the dipole level which is the result of a simple correction of the received level by 20log(distance). The dipole level is much lower at the low frequency end than the monopole level.

Results

Figure 6 shows the distance over time and the spectrogram associated with passage of the ship. Closest point of approach is slightly earlier than the minima of the hyperbolic structures which is due to the fact that the GPS antenna of the ship is forward of the main noise source, in this case the propeller. The hyperbolic structure is due to the radiation of a point source close to the surface and represents the changing interference pattern of the various propagation paths. It is also a clear indication that the propeller was cavitating.

The broad band structure is overlaid by horizontal lines indicating harmonics of diesel engine rotational frequency (main engine) and half rotational frequencies (4-stroke auxiliary diesels operating at 900 rpm).

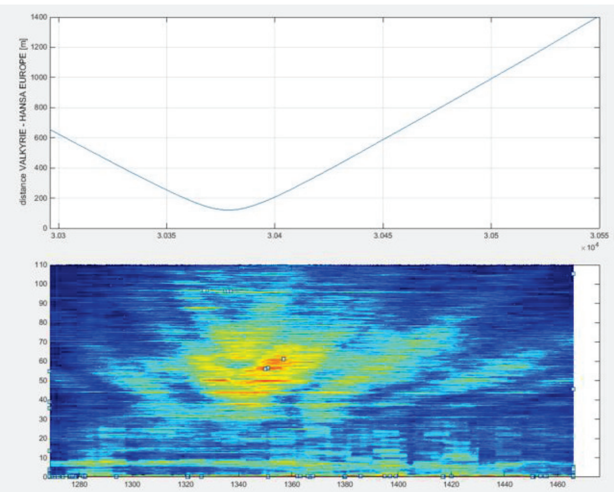

Figure 6: Distance over time and spectrogram at 75 rpm

Figure 7 shows the source levels of the ship calculated from measured (received) level and application of the transmission loss in Figure 5. It appears that only the frequency range between 20 and 90 Hz is affected by speed.
Above 100 Hz the typical structures of diesel engine noise become apparent which may be the reason that decreasing cavitation does not result in similar reduction of radiated noise. The strong tonals between 40 and 50 Hz in the 44 rpm condition can be attributed to the auxiliary diesels which operate independent of ship speed. They are masked by cavitation in the 75 rpm condition.
At 400 to 500 Hz a maximum in the spectrum is observed which seems to be little affected by speed. The cause of the signal is unknown. Investigation in the time domain reveals that the noise is highly fluctuating without periodic features.

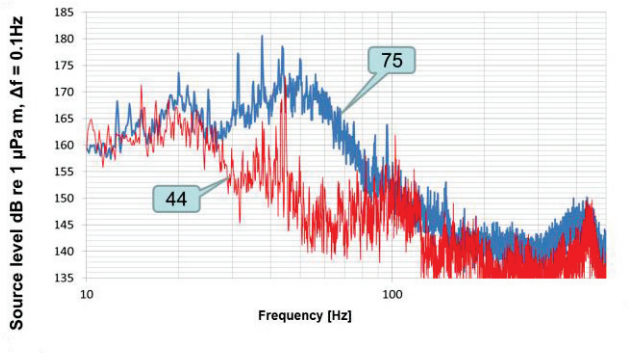

Figure 7: Source level for conditions 44 and 75 rpm

Figure 8 shows a comparison of the source level as measured onboard and in the Channel. Broad band levels between 10 and 300 Hz are very similar. The level at the blade rate harmonics at multiples of 6.25 Hz are less pronounced in the Channel measurement. The maximum at around 400 to 500 Hz is not observed onboard but there is a maximum of similar character at 300 Hz. Above 300 Hz the level onboard is very much lower which indicates that the propeller is not a dominating source for the overall level of the ship above that frequency. The characteristic hump at 40 to 50 Hz which can be observed in almost all ships with cavitating propellers shows clearly in both measurements.

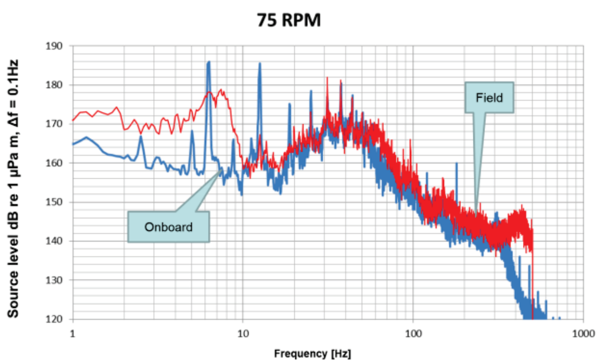

Figure 8: Comparison of source level from onboard measurement and measurement in the Channel

Discussion

There are many effects which made this comparison difficult such as:

- The concept for the source level is not completely physically sound
- The assumed source depth is not ascertained
- There were four years between the measurements. There may have been changes in influencing parameters in the meantime

- The draft of the vessel differed by about 1 m
- The surface during the Channel measurement was very rough. This disturbs the reflection of sound and may weaken the arriving sound wave reflected at the surface leading to different interference behavior at the receiver
- The reflecting properties of the bottom and the contributing paths are assumptions

Despites of the uncertainties which are difficult to quantify the match between the two source levels in the range where the propeller dominates radiated noise is impressive and may give rise to the expectation that the uncertainties are of less influence than anticipated. To support such an assumption more of these comparisons should be done.

Outlook

Further work involves model testing for the same ship and propeller to compare the radiated spectrum for model and full scale. If this compares favorably model scale testing may be the means to investigate the peculiar appearance of the spectrum as seen in Figure 8, understand it and find means to reduce also the broad band level.

It may further be tried to do similar measurements with HANSA EUROPE's sister ship which has a different propeller design.