24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

A COMPARISON OF METHODS FOR MEASURING SHIP SOURCE LEVEL IN SHALLOW WATER

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The noise radiated by shipping is potentially a contributor to ocean environmental noise, especially with the ever-increasing volume of commercial ship traffic. Values for the noise radiated by commercial ships are generally not available, but such data are required if assessments are to be made of the impact of individual ships (for example when operating in sensitive areas). In addition, if noise mapping is to be undertaken of noise from shipping lanes, values are required of source level for use in propagation models. Measurement standards have been developed for measurement of radiated noise by a ship in deep water (ISO 17208-1:2016). No such standards yet exist for measurement of ships in shallow water, but this is already the subject of active work in ISO TC43 SC3 WG1. In this paper, a number of potential methodologies for measuring ships in shallow water are presented, and the advantages and disadvantages of each are discussed. In order to determine the source level from shallow water measurements, the sound pressure levels measured by hydrophones must be converted to a source level using an appropriate propagation models. In this paper, a number of approaches for addressing this issue are described, and some sources of uncertainty are identified.

Keywords: Ocean Noise, Ship Noise, International Standards

1. Introduction

There is evidence that man-made noise in the oceans has increased in recent decades due to the increased exploitation of oceans [1], for example, for transportation, development of offshore energy, and extraction of natural resources such as oil and gas. Shipping noise has become recognised as a potentially significant contributor due to the increase of shipping traffic, which has largely scaled with world GDP [2]. The increasing background noise level is potentially detrimental to marine life, for example by masking the communications between members of the same species.

To fully understand the effect of noise from ships requires accurate knowledge of the noise levels radiated by individual ships, which in turn requires agreed measurement methods and common metrics to quantify the noise. This may be required to assess the environmental impact of specific vessels entering sensitive areas, but is also needed for inputs to noise mapping processes, where a prediction of the noise levels in a region is made using modelling. This is very demanding since there are huge number of ships in the oceans but very few with known source levels.

These needs have led to development of measurement standards, but so far these have not addressed measurement in shallow water.

2. Measurement issues

One of the first issues to address is how to specify the acoustic output of a ship. Traditionally, this has been done in terms of the Radiated Noise Level (RNL), a quantity determined by measuring the sound pressure in the acoustic far-field using one or more hydrophones and then correcting back to the acoustic centre of the vessel by applying a correction for spherical spreading. This method has been become the basis of two measurement standards: including ANSI S12.64 (2009); and ISO 17208-1: 2016 [3, 4]. Here, measurements are made in deep water (defined as deeper than about 300 m or sufficiently deep that the interaction of sound with the seabed may be neglected) using up to three hydrophones (arranged at different elevation angles to the water surface), and the range correction for spherical spreading is applied to a measured received signal level to derive the radiated noise level for a ship under test.

Work is currently underway in ISO TC43 SC3 WG1 to prepare a part 2 for ISO 7208 where the RNL measured according to part 1 may be converted into a monopole source level with a relatively simple equation that takes account of the interaction of the radiated sound with the water surface. The source level (or source level spectrum) is a simplified metric to describe a source as complicated as a ship. However, in the acoustic far-field, where the sound waves appear to diverge from a point in the medium, the source level is commonly used as the metric to describe the acoustic output of sources in water. The term derives from use in the sonar equations and is only used in underwater acoustics, whereas in air acoustics sound power level is the common source term (source level may be related to sound power through the acoustic properties of the medium and the source directivity).

Standardisation so far has focused on measurements in deep water. However, measurement procedures are also needed for shallow water. Deep water measurements are not always practicable, and sufficiently deep water is not always available. Determining the source level in shallow water has some significant challenges:

- To calculate the source level requires a relatively sophisticated propagation model which can account for the interaction of the sound with the seabed;
- Knowledge is required of the environmental parameters which govern the propagation of the sound in shallow water, including the seabed properties and surafce roughness;
- The value of the calculated source level is dependent on the depth that is assumed for the acoustic centre of the source (this is also true of deep water measurements of source level);
- Shallow water can sometimes exhibit strong tidal currents, and rapid changes in water depth.

There are some practical advantages to making measurements in shallow water. The main advantage is that hydrophones may be deployed from the seabed, potentially enabling a greater precision in the knowledge of the hydrophone position and allowing for the possibility of a number of hydrophones to be deployed simultaneously at a number of ranges from the source.

3. Possible measurement configurations

There are a number of different configurations to measure ship noise in shallow water. In each, the vessel under test sails past measurement station(s) and the sound radiated by the ship is measured during the passage of the vessel.

The simplest is a single measurement location. This is the easiest configuration to deploy, requires the least equipment and is the least expensive to resource. However, there are disadvantages in that the sound field is sampled in only one location, and no empirical check is possible on the sound propagation.

Sampling the sound field is several locations is advantageous in that an empirical measure of the propagation is possible by simultaneous measurement of the sound field using multiple recording stations. The source level may then be calculated from the received level at each measurement locations using an appropriate propagation model and multiple estimates of the source level may be obtained. The measurement instrumentation may be hydrophones deployed from a small research vessel, or more likely, autonomous recorders deployed on the seabed in specific locations within a few hundred metres of the closest point of approach of the vessel.

An alternative approach is to use one measurement station, but vary the source receiver distance by having the vessel sail past at different ranges. The results from different passes are then averaged to form an estimate of the source level. This requires fewer measurement deployments and less equipment, but has the disadvantage that the vessel output may very between passes.

The spatial distribution of underwater sound pressure is depth dependent. A stronger dependence on depth is present in the upper quarter of an acoustic wavelength in the water column. For this reason, the hydrophone should not be placed close to the water surface. The measurement stations may also enable the field to be sampled throughout the depth of the water column. This requires more than one hydrophone at each measurement location. This has several advantages: (i) it enables some redundancy - if one hydrophone or measurement channel fails, there is a back-up; (ii) increased dynamic range - two hydrophones with different sensitivities may be chosen to mitigate the requirement for a larger dynamic range than can be covered by a single measurement hydrophone or channel; spatial averaging - use of more than one hydrophone allows averaging of the measured data obtained from different depths.

The measurement stations themselves can consist of different categories of deployment. Vessel-based deployment involves deployment of hydrophones (either individually, or in arrays) from a vessel, with the analysis and recording equipment remaining on the vessel, which can be either anchored or drifting. The method has the advantage that deployments can be quick and mobile, and a relatively large area can be covered fairly cost-effectively. The risk of losing instrumentation is low, the data can be monitored as they are acquired, and instrument settings can be adjusted in real time to provide the optimum settings for high quality data (for example to avoid saturation and distortion). Vessel-based deployments can suffer from certain types of platform-related noise. Static systems provide a measurement at a fixed range and a bottom-mounted deployment is preferable to a surface deployment to minimise parasitic signals from the influence of surface wave action, to keep the hydrophone away from the pressure-release water-air surface, and to minimise disturbance by surface vessels. Cost effective solutions for most deployments are autonomous recorders, which are archival and store data on memory cards or local drives with the data only available after recovery. Recovery requires either an acoustic release system or a surface buoy deployed from a seabed anchor, which enables the recorder to be hauled to the surface.

A ship is a very complex noise source that may have multitude of radiation centres with different directivities. However, for simplification, in the far-field it is assumed that the ship noise is from a point source located at a specified depth below the surface. In a typical measurement procedure, the radiated sound from a ship is recorded by the hydrophones for a number of ship passes. In order to determine the averaged sound pressure level, the one third octave band signal spectrum level of the received signal corresponding to a time window of the ship passing over a track length of ±30° with respect to the CPA from the nearest measurement hydrophone, is calculated firstly for all the hydrophones. The received signal level is then adjusted for background noise, if necessary, before the sensitivity of the hydrophone and the gain of the data acquisition system are applied to obtain the received sound pressure level (RL).

The individual source level from the ship to one hydrophone is obtained by adding the propagation loss (PL) between the source and the hydrophone to the RL of the hydrophone for all the hydrophones.

Finally, the ship source level is obtained by a power average of the individual source levels from all hydrophones from one run and then by an average of the source levels from all the runs.

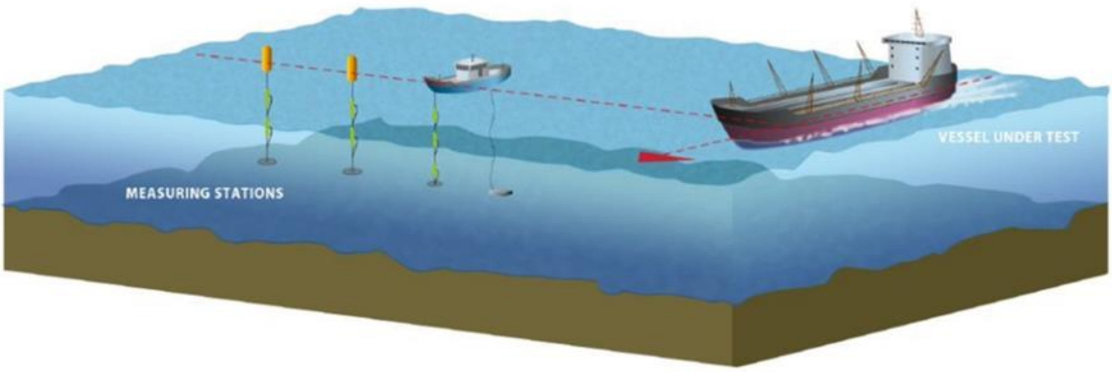

Figure 1. A schematic diagram showing one possible measurement configuration with multiple static recording stations for simultaneous measurement.

The largest source of uncertainty in measuring ship noise in shallow water is from the uncertainty in the propagation loss. The multiple recording stations allow multiple estimates of source level and an empirical check on the propagation loss. An alternative method that has been adopted is to use a calibrated source to determine the transfer function of the shallow-water channel. Such a source must be capable of generating acoustic signals at frequencies commonly encountered from ships: 40 Hz to 10 kHz, and ideally be towed at the correct depth below the water surface as the acoustic centre of the vessel under test.

The propagation model used can any of a number of suitable models that are appropriate for low frequencies in shallow water channels for ranges of only a few hundred metres. Examples include wavenumber integration, adiabatic normal mode approximation [5].

To assess the uncertainties in the propagation modelling, Monte Carlo simulations may be carried out to examine the effects of variable environmental conditions on the measured source level of a ship in a shallow water channel with specific configurations. This has been done [6, 7] and it is seen that the variations caused bias and spread in source level with a maximum standard deviation less than 2 dB at third-octave band frequencies between 63 Hz to 50 kHz in this case. Such Monte Carlo simulation is very useful to generate the required mean value of the source level and the uncertainty.

Work is now underway in ISO TC43 SC3 WG1 to develop a part 3 of ISO 17208 to cover the procedures for measuring ship noise in shallow water. This work should develop a standard for publication by 2019.

4. Acknowledgements

This production of this paper has been funded by National Measurement Office of the United Kingdom Department for Business, Energy, and Industrial Strategy.

The authors acknowledge many fruitful discussions with colleagues and friends, including members of ISO TC43 SC3 WG1. In particular, Christ de Jong (TNO), Anton Homm (WTD71), Christian Audoly (DCN), Victor Humphrey (University of Southampton), Mike Bahtiarian (NCE).

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