METHOD FOR LF CALIBRATION IN CONFINED MEASUREMENT TANK

Per Abrahamsson, Óskar Ásgeirsson, Victor Borén, Bo Lövgren

Saab Dynamics, SE-581 88 Linköping, Sweden

Per Abrahamsson
Saab Dynamics
SE-581 88 Linköping, Sweden
Phone: +46 13 18 35 83
E-mail: per.abrahamsson@saabgroup.com

Abstract: Calibration of hydrophones and transducers is essential for measurements in the underwater domain. When measuring low frequency, below 4 kHz, transducers and hydrophones in a confined test tank problems occur due to the long wavelength. These problems occur mainly due to the multi-path that occurs in the tank. One way to eliminate this problem is to do the measurements in free-water where the risk of multi-path is reduced. However, a free-water measurement have other drawbacks that can be eliminated in controlled test environments such as a tank. In order to do the measurements in the controlled environment of a tank the impact of the tank has to be eliminated. In this paper a previously presented method is used together with some adaptations. The method is based on that the one can see the tank as a transfer function between the transducer and the hydrophone. If the transfer function can be estimated then the impact of the tank can be eliminated. To verify the method both free-water and tank measurements where performed. To be able to estimate suitable positions for both the transmitter and hydrophone a numerical wave propagation model was used. The result from the model was validated with a series of measurements to estimate the methods robustness against positioning errors.

Keywords: *Test-tank, Low frequency, Calibration, Measurement*

PROBLEM DESCRIPTION

To have calibrated and characterised equipment is an essential matter in the underwater domain. To get good measurements one should try to eliminate all external impacts on the measurement. For low frequency systems, in this paper low frequency is assumed to be frequencies below 8 kHz, this can be costly or difficult. This is due to the large wavelength of the system.

A measurement is performed either in a controlled environment of a test tank or from a ship. Ship measurements can be costly and the result can be degraded by unknown external factors. In tank measurements the test environments is known and may be controlled. However, test tanks often have a limited size, which can have a negative effect on the result for low frequencies.

The method tested in this paper is that the effect of the test tank is considered as a transfer function of the acoustic signal [1]. If the transfer function for a test object is known, a similar object can then be measured in the test tank.

METHOD

The method used to calculate the transmission sensitivity is based on

$$SL_i = L_{HT} - S_H + 20\log_{10}(R_i), \quad (1)$$

where SL_i is the source level, L_{HT} is the measured output from the receive hydrophone, S_H is the hydrophone sensitivity and R_i is the distance between the two objects. All terms except R_i are frequency dependent [1], [2].

Measurements are done both in a sea measurement and in the confined space of the test tank. The results SL_1 and SL_2 are then used to calculate the transfer function of the test tank, F:

$$F = SL_1 - SL_2. \quad (2)$$

The source level of a similar test object can then be calculated with:

$$SL = SL_{Measured} + F. \quad (3)$$

There are a number of error sources in this method:

- Time dependent path fluctuations in the sea measurement caused by altering wave patterns at the surface.
- Null-anomaly in the sea measurement caused by interference patterns.
- Position errors in the test tank. Due to the multi-path propagation in the test tank there is a complex interference pattern in the tank, which results in a high sensitivity for position errors in the method.
- Position errors in the sea measurement.

During the validation of the method, care where taken to reduce the external factors that can be observed in sea measurements.

NUMERICAL MODEL

In an attempt to eliminate the need for a sea measurement a numerical wave propagation model for the test tank environment was developed using a MATLAB toolbox [2]. The toolbox uses an optimized implicit method to solve the wave equation and uses a perfectly matched layer (PML) which absorbs the energy when it reaches the boundary of the computational domain. Waves in a heterogeneous medium where modelled using:

$$\frac{\partial \boldsymbol{u}}{\partial t} = -\frac{1}{\rho}\nabla p + \boldsymbol{S_F}, \tag{4}$$

$$\frac{\partial \rho}{\partial t} = -\rho_0 \nabla \cdot \boldsymbol{u} + S_M, \tag{5}$$

$$p = c_0^2 \rho. \tag{6}$$

Here $\boldsymbol{S_F}$ is the body force input to the system, N/kg or m/s^2. S_M is a mass source term and indicates how much mass per unit volume per second, kg/(m^{3}s), that is added to the system.

The PML is a thin absorbing layer, at the boundary of the domain, which uses a set of nonphysical equations to cause anisotropic absorption. The layer provides sufficient attenuation to prevent waves from being reflected back into the medium. The toolbox uses the Bergener's split-field formulation of the PML.

The source used in the simulation is a cylinder shaped transducer matching the physical test object. The transducer was set to produce an omni-directional sinus signal.

The computational grid was divided into two mediums, water and air. The set-up was so that the air was positioned around the water volume. Due to the large difference in acoustic impedance between the mediums causes only a small amount if the acoustic energy is transferred into the PML.

The mesh for the calculation were chosen as

$$f_s = \frac{c}{max(\Delta x, \Delta y, \Delta z)} \geq 2f, \tag{7}$$

where f is the frequency of interest. A too coarse mesh will result in an inaccurate result [3]. Since the frequency of interest for the conducted trials was between 1 and 4 kHz a mesh size of 0.05 m was chosen.

To get a stable solution a suitable time step has to be chosen. The Courant-Friedrichs-Lewy stability criterion was used to get an appropriate time step. The criteria states that the solution should travel faster than the wave propagation. This can be checked with

$$0 \leq \frac{c\Delta t}{min(\Delta x, \Delta y, \Delta z)} \leq CFL_{max}, \tag{8}$$

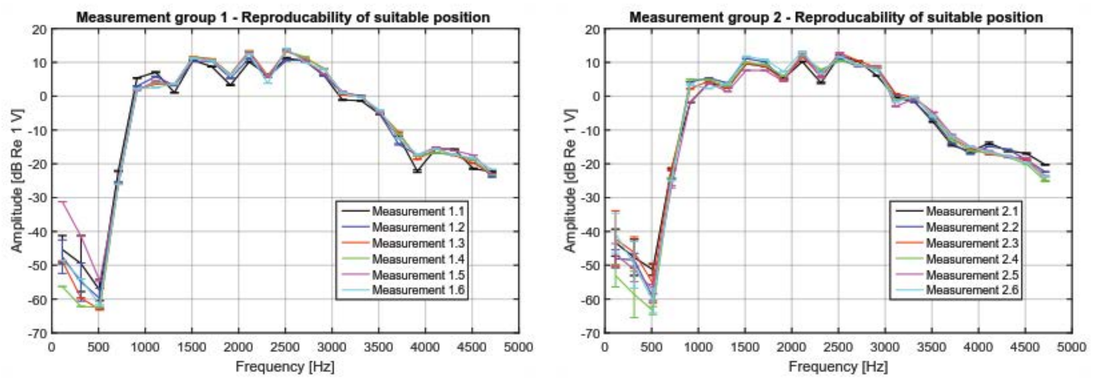
where CFL_{max} is the Courant number. To ensure stability the Courant number should be less than 0.5 for a three dimensional solution [4].

Applying the criteria in the experiment to equation (8) gives a Δt of 1.67 µs. These results now gives the set-up that enables the comparison between the numerical method and the measurements.

RESULT

To test the theory and the numerical method several measurements where done including sea measurements. The purpose of the measurements was to validate method and explore the stability of it.

To ensure the stability and repeatability of the method several measurements were done in the tank at different times, see Fig 1. The data shows that the method is repeatable and stable.



(a) Measurement group 1 (b) Measurement group 2

Fig. 1: Results from measurements performed at the chosen suitable location. Group 1 and 2 are measurements performed at different times.

A sensitivity comparison was also made for the positioning of the test object. The comparison was done in two steps. In the first step different positions in the test tank were used for the transmitter and receiver. Each measurement was repeated multiple times to test the sensitivity for that position. The trials showed that there was a difference in the repeatability between different positions. In the second step the most consistent position from step 1 was chosen and small variations in the position were made to see how this affected the result. Relatively large measurement differences, up to 5 dB rel. 1 V, were measured even with small changes.

Using the position from step 1 measurements were done to collect data and compare it to the sea measurements, see Fig 2. To enable comparison all data is normalized according to

$$SL_{Norm} = L_{HT} - S_H + 20\log_{10}(R) - SL_{Comp}, \tag{9}$$

where SL_{comp} is a factor that compensates for different level settings at sea and in the tank. The most obvious difference between the sea and tank measurements are the peaks at 1.6 kHz, 2.1 kHz and 2.5 kHz. These peaks come from the positioning in the test tank and move in frequency with the tested position which was observed in step 1 above.

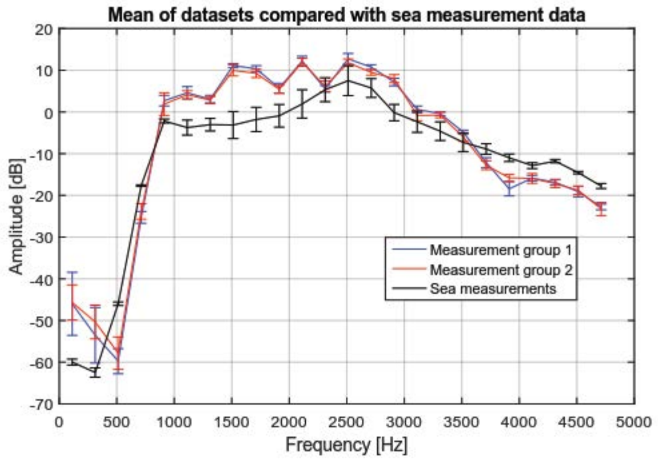


Fig. 2: Results from group 1 and 2 compared with sea measurement, normalized according to (9). [dB rel. 1 V]

A transfer function for the test tank could then be calculated from the data, see Fig. 3. This function could then be used to measure similar test objects.

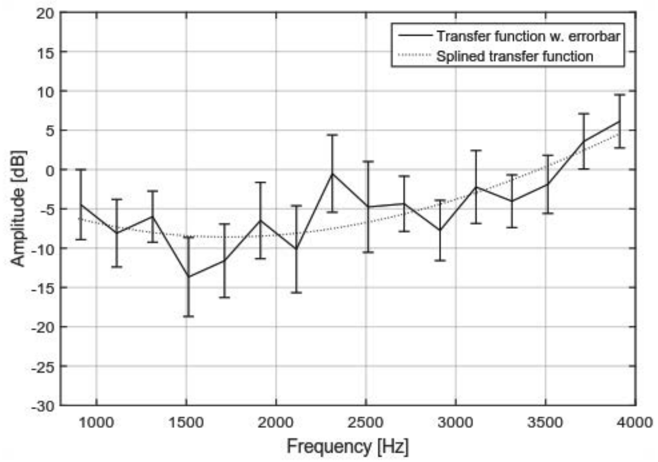


Fig. 3: Calculated transfer function. [dB rel. 1 V]

A transfer function was also calculated from the numerical method. The transfer functions are compared in Fig 4. As one can see, there are differences in the functions. Some causes of this that have been observed is the simplified model of the tank and that the numerical model only is a 2D model.

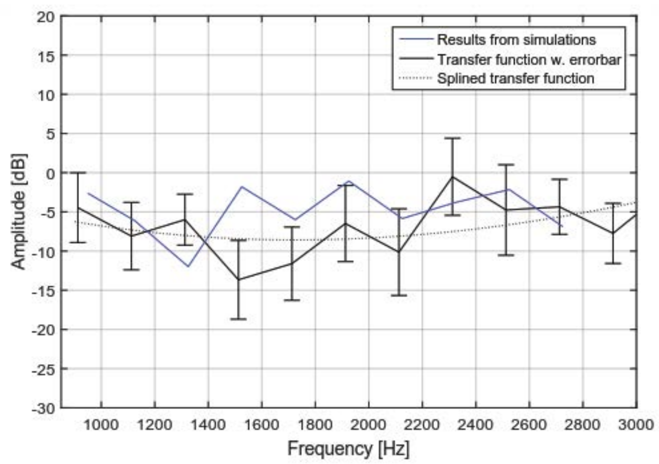


Fig. 4: Comparison between real results and the numerical method. [dB rel. 1 V]

DISCUSSION

The experiment shows that it is possible to use this method to measure the acoustic properties in a confined tank even for lower frequencies. However, the method requires care when choosing the placement of the test object and the measurement system. When using the method for a new object the placement of the object in the test tank has to be re-examined to get good quality in the measurement, see the sensitivity measurement above.

Due to the complex environment in the tank more consideration has to be taken to the geometry in the model to get to a level where the sea measurement can be excluded. The numeric calculation method must be enhanced with higher dimensions and a more detailed environment, especially mounting devices and tank structure, for it to replace the sea measurement.

Further work with other shape and frequencies equipment to further validate the method should be performed.

REFERENCES

[1] **Bo Lövgren**, Low Frequency Tank Calibration by Comparison. Presented at the inter.noise conference in Hamburg 2016

[2] **B. E. Treeby and B. T. Cox**, k-Wave: MATLAB toolbox for the simulation and re-construction of photoacoustic wave-fields. J. Biomed. Opt., vol. 15, no. 2, p. 021314,2010

[3] **National Instruments. Aliasing**, Accessed: 2017-03-07 from: http://zone.ni.com/reference/en-XX/help/370051V-01/cvi/libref/analysisconcepts/aliasing/

[4] **Peter J. Oliver**, Introduction to Partial Differential Equations. Springer, 2014. isbn: 9783319020893