Hydro acoustic transducer’s calibration by the reciprocity

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Abstract. This paper presents a calibration technique of underwater acoustic transducers, hydroacoustics, known as three-transducer spherical-wave reciprocity and performs an assessment of the type B standard uncertainty of the results obtained for the frequency measurement used.

1. Introduction
In the various activities of ocean exploration as oceanographic research, hydrographic surveys, underwater communications and sea surveillance, all components of hydroacoustic systems and their combinations should be capable of providing data according with acceptance criteria that ensure that the measuring instrument or standard has the accuracy required for the intended use. Metrologically, the way to ensure the required accuracy is, in general, through proper and periodic calibration according to specific technical standards, such as IEC 60565 [1].

2. Theoretical basis
The transducers used in underwater acoustics can be divided into three groups:
- Projectors (P) are built to be transmitters of acoustic waves and transmit sound power to the middle.
- Hydrophones (H) are constructed to be receivers of acoustic waves and have the characteristic high sensitivity of detection.
- Reciprocal transducers (T) can be used as transmitters or receivers.

The calibration of transducers can be performed (primary) absolutely, as known through calibration by reciprocity with spherical waves, based on reciprocity technique.

2.1. Reciprocity
In order for a transducer be reciprocal it must have the following properties: being a linear, reversible and passive element. The parameter of reciprocity J is constant for a given frequency [2], and relates the reception sensitivity (M) with the transmission sensitivity (S) of a piezoelectric element, defined as:

\[ J(f) = \frac{M(f)}{S(f)} = \frac{2r}{\rho f} \] (1)
where:
\( r \) is distance from the spherical wave source
\( \rho \) density of the medium (water)
\( f \) the vibration frequency

2.2. Three-transducer spherical-wave reciprocity

Three transducers are needed in this calibration technique by reciprocity to determine the sensitivity of a free-field hydrophone: hydrophone (H), a projector (P) and a reciprocal transducer (T). Three measurements are also needed, as shown in Figure 1.

![Figure 1 – Three steps of calibration by reciprocity](image)

For a pair of transducers, the acoustic transfer impedance \((Z)\) is defined as the ratio of the open circuit voltage \((V)\) at the receiver, induced by the excitation current \((I)\) through the transmitter device [3]:

\[
Z = \frac{V}{I}
\]

(2)

Voltage induced on the hydrophone (H) is the product of its reception sensitivity \((M_H)\) by the pressure received in his face \((p)\). As the pressure generated by the projector (P) at a separation distance \((d)\), the product of the sensitivity of the transmission \((S_P)\) by the excitation current \((I_P)\) divided by \((d)\) in case where the spherical wave acoustic pressure decays to half with twice the distance, we have:

\[
V_{PH} = pM_H = \frac{S_PI_PM_H}{d}
\]

(3)

In an analogous way we obtain \(V_{PT}\) and \(V_{TH}\). Thus we have a system with three equations and four unknowns variables \((M_H, S_P, M_T, S_T)\). Using the reciprocity parameter for the reciprocal transducer (T), the equation (1), is obtained the fourth equation and can determine all parameters of the transducers, as in this case:

\[
M_H = \left( f_d \frac{Z_{PH}Z_{TH}}{Z_{PT}} \right)^\frac{1}{2} = \left( \frac{2d^2V_{PH}V_{TH}}{\rho f^3V_{PT}I_T} \right)^\frac{1}{2}
\]

(4)

Rewriting the equation (4), so as to visualize the measurement variables, we have:

\[
M_H = \sqrt{2d} \cdot \rho \cdot f^{-\frac{3}{2}}V_{PH}^{\frac{3}{2}}V_{TH}^{\frac{3}{2}}V_{PT}^{\frac{3}{2}}I_T^{\frac{3}{2}}
\]

(5)

From equation (5) evaluation of the standard uncertainty of type B was taken.
3. Materials and methods
The experiments were performed in hydroacoustic tank tests at the Institute of Marine Research (IPqM), in Rio de Janeiro, RJ, Brazil. That non-anechoic freshwater tank has dimensions of 10 meters in length and 10 meters wide by 5 feet deep (Figure 2). The following measuring instruments and accessories have been used: two reciprocal transducers Model 1001, one as a projector (P) and another as reciprocal (T) and a hydrophone (H) Model 1032, all manufactured by International Transducer Corporation (ITC); preamplifier and amplifier dedicated (Scientific-Atlanta, USA); model DSO6032A oscilloscope and signal generator model 3325A, both from Agilent Technologies. For control, data acquisition and processing a routine done in LabView™ (National Instruments, USA) was used.

The details of the method used in this work can be found in [4]. The transducers were prepared, and their surfaces were clean and free of air bubbles, so that it ensures the perfect coupling between the acoustic transducer and the medium (water). The transducers were positioned symmetrically at 96 cm from each other and the half depth of the tank to minimize the effects of reflections on the walls.

The excitation currents were measured by the voltage drop across a resistor shunt in the amount of 1.82±0.01Ω.

4. Results
The speed of sound was measured obtaining 1.488 ± 0.15 m/s under the experimental conditions. According to [5], the density of fresh water is 997.77 ± 0.96 kg/m³ for the range of temperatures observed during the experiment (21°C e 23°C). The separation distance between the transducers, as measured by time of flight of the signal was 0.96 ± 0.02m. We carried out a calibration of the reception sensitivity (M_H) of the transducer ITC1032 in the range of 3 kHz to 15 kHz in steps of 1 kHz, obtaining the result shown in Figure 3. In this figure the sensitivity of the hydrophone is also presented, according to the manufacturer data.

4.1. Evaluation of standard uncertainty type B
As non-repetitions of the same experiment were performed, an assessment of uncertainty type B from the specifications of the instruments used and the uncertainties in the variables in (5) was taken, using the Guide to the Expression of Uncertainty in Measurement, GUM [6].
Table 1. Uncertainty ($M_{th}$) of the transducer ITC1032

| freq.[Hz] | sup [dB] | $M_{th}$ [dB] | inf [dB] |
|-----------|---------|---------------|---------|
| 3000      | -192.1  | -192.5        | -192.9  |
| 4000      | -192.5  | -192.9        | -193.3  |
| 5000      | -192.6  | -192.9        | -193.3  |
| 6000      | -193.1  | -193.4        | -193.8  |
| 7000      | -193.3  | -193.7        | -194.0  |
| 8000      | -193.7  | -194.0        | -194.4  |
| 9000      | -194.0  | -194.3        | -194.7  |
| 10000     | -194.3  | -194.6        | -195.0  |
| 11000     | -194.6  | -195.0        | -195.4  |
| 12000     | -195.0  | -195.4        | -195.8  |
| 13000     | -195.2  | -195.6        | -196.0  |
| 14000     | -195.4  | -195.8        | -196.1  |
| 15000     | -195.5  | -195.8        | -196.2  |

Figure 3 – Curve ($M_{th}$) of the transducer ITC1032

5. Analysis

The IEC 60565:2007 [1] tells that the standard calibrations for reciprocity in free field is carried out by observing the requirements of the standard and taking into account the parameters described in Annex D have uncertainties typically less than 1 dB. Already in reference [7] the authors performed calibrations on 2 methods, independent laboratories obtaining uncertainties typically less than 0.5 dB. Our findings are similar to [7] and are well below the typical uncertainties [1].

This is justified by the fact that this work was not done study of uncertainty of type A. Additionally the system used has adequate accuracy for the method studied since it results in a low natural component of Type B uncertainty.

Regarding the results, Figure 3 shows the results obtained with the calibration comparing them with the specifications of the manufacturer. It is observed that in all the frequencies results differed less than the respective uncertainties Type B. This shows that the method was consistent with the expected results for the calibration of the hydrophone.

A number of factors can influence the calibration results, such as:

- The separation between the transducers must be controlled;
- The reflections on the walls of the tank;
- Electrical calibrations of instruments;
- Monitoring of water temperature.
These parameters were considered most relevant in the uncertainty model developed in this study and were considered in this model.

6. Conclusion
The method of absolute calibration of hydroacoustic transducers was implemented successfully. This is a validated method of long standing, including an international standard for their implementations have been used. The newness of this work lies in the fact that this implementation had never been held in Brazil and open space for future developments in underwater acoustics.

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