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Calibration of Underwater Sound Transducers

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Abstract. The techniques of calibration of underwater sound transducers for far-field, near-field and closed environment conditions are reviewed in this paper. The design of acoustic calibration tank is mentioned. The facilities available at Naval Physical & Oceanographic Laboratory, Cochin for calibration of transducers are also listed.

1. Introduction

Conventional electromagnetic energy sources are not deployed for underwater communications are electromagnetic energy cannot propagate underwater over ranges in excess of a few tens of meters due to high absorption in sea water. Traditionally sound has been the most favoured form of energy for various undersea applications. Underwater acoustic measurements thus attain a special significance for a marine Scientist for ocean exploration or exploitation. While the role of underwater acoustics cannot be over emphasized in its relation to various applications of naval warfare like target detection, location and classification etc., the underwater electro-acoustic measurements have a multitude of non-military applications in the fields of fisheries, marine geophysical prospecting including offshore drilling platforms, exploration of marine rocks and sediments, bio-acoustics, underwater communications and cavitation.

The underwater acoustic measurements broadly cover the fields of transducers, measurement of radiated noise and self noise of ships and acoustic evaluation of various passive materials like metals, plastics, fibre-glass reinforced plastics, rubbers, elastomers, acoustic polymers, transducer liquids, etc. The different techniques of calibration of underwater sound transducers for free-field, far-field are described alongwith the concepts of near-field tecniques and those for closed environment, as in small closed tanks. The design of an acoustic calibration tank is explained.

The facilities available at Naval Physical & Oceanographic Laboratory (NPOL) Cochin for calibration of transducers are also listed.

2. Calibration of Transducers

Acoustic calibration of any underwater system invariably involves measurement of open circuit output voltage of a transducer to determine free-field acoustic pressure in water. It means the transducers used for this purpose are to be calibrated. Various calibration procedures may differ in details due to frequency, size of transducer, environment, purpose and so on.

Calibration Parameters

The calibration of a transducer essentially consists of determining three important parameters, viz., receiving sensitivity, projector response and impedance. Any other parameter can be computed from sensitivity or response and impedance. Phase has very little application in underwater acoustic mearurements.

The free-field voltage sensitivity of a hydrophone is the ratio of the open circuit output voltage to the free-field sound pressure in the undisturbed plane progressive wave. The transmitting current (or voltage) response of a projector, called projector response, is the ratio of sound pressure at a distance of one meter from the acoustic centre of the transducer to the signal current flowing into (or the voltage applied across) the electrical input terminals. These two electro-acoustic parameters of a transducer are measured as a function of frequency, signal level, signal type, environmental factors, orientation and so on. The electrical impedance is a quasielectro-acoustic parameter of a transducer as it is a function of the acoustic characteristics of the medium into which the trasducer is radiating sound. Parameters like directivity factor, electro-acoustic conversion efficiency, etc. are derived from the above parameters.

Classification of Calibration Procedures

The calibration of a transducer is classified into Secondary or primary calibration based on the principle whether a calibrated standard transducer is used for the purpose or not. The primary calibration that does not deploy a standard transducer can be reciprocity calibration, based on classical reciprocity principle in acoustics, or physical calibration in which the sound pressure at the hydrophone is calculated from the measurement of physical parameters such as displacement, velocity, acceleration, chamber compliance, etc. Null trasnducer, pistonphone, vibrating column etc. are some of the examples in this connection. The test hydrophone is calibrated in comparison with a standard hydrophone in a secondary calibration.

The limitations of the sound field lead us to further distinguish three types of calibration. Free-field calibration is one where the boundaries of the sound field do not affect the free-field conditions. Small chamber calibration is one where the largest dimension of the chamber is sufficiently less than one wavelength of the sound. Finally, near-field calibration is one where the available water volume is too small to avoid boundary effects and to satisfy far-field criteria for the given size of a transducer.

Proximity Criteria

Proximity criteria define the distance at which Fresnel Zone or near-field endsand the Fraunhofer zone or spherically divergent far-field begins. There are two proximity criteria characterised by two wave parameters—phase and amplitude.

$$d \quad l^2/\lambda$$

$$d \geqslant l$$

where d is the distance between projector and hydrophone and l is the largest dimension of the finite transducer. For non-planar transducers like thick cylinders and for directivity pattern measurements, a criterion

$$d \quad 5\,D$$

is considered adequate in most practical cases, where D is diameter of thick cylinder.

Free-Field Calibration

Both primary and secondary calibrations are carried-out under free-field conditions. Free-field reciprocity calibration is a primary method that can be used above 1 KHz. It is based on the reciprocity principle that for any reciprocal transducer, the free-field sensitivity (M) divided by the transmitting current response (S) is equal to a constant value known as free-field reciprocity parameter (J).

This technique uses at least three transducers—a projector, a hydrophone and a reciprocal transducer. Out of these three transducers, with different combinations of projector—hydrophone pairs, three independent transfer impedance magnitudes are obtained. If the quotient and product of these quantities are known, the receiving sensitivity and transmitting response can be calculated.

Projector response of a transducer can be calculated by this method. Alternatively, the sound pressure at one meter from the projector is measured with the help of a standard hydrophone and the response is calculated for unit current or unit voltage excitation.

Free-field comparison calibration can be carried-out above 100 Hz after satisfying proximity criteria. It is a secondary method, but it is a simple, easy, quick, reliable and accurate.

Pulse Technique[1].

Both the principles of primary and secondary calibration require a free-field environment. Though many natural sites like hydro-electric reservoirs, lakes, ponds and sometimes open sea are used for calibration purposes, ambient noise is increased by water transport, movement of ships, rain, wave motion etc. Any true free-field conditions are disturbed by currents, temperature gradients, marine life, bubbles, pollutants, shallow depth and so on. Therefore anechoic water tanks with sound absorbent linings on all walls and bottom are often used. But these tanks offer problems of size for low frequency operation and problems of proper absorbent linings for wide band operation and their proper adhesion to walls etc. These problems can be overcome by using a pulse technique to facilitate calibration of hydrophones in a relatively small water tank.

In a continuous wave transmission, direct signal from projector to hydrophone and reflected signals from boundaries overlap and measurements cannot be carried-out. When a pulsed sound or in other words, gated single frequency signal is transmitted, it provides a time separation for these two types of signals thus facilitating proper calibration. It therefore eliminates the effects of interference from boundaries, standing waves and electrical cross-talk. Thus the pulse technique is the essential technique of measurement in free-calibration of transducers.

Filter characteristics, transducers and non-specular reflection characteristics of boundaries distort the pulse shape. When a pulsed sound is passed through a transducer, it takes a finite period of time to reach its steady state amplitude. After the signal is switched off, the system continues to oscillate or ring at its resonance frequency decaying exponentially. The initial transient and the decay transient will be of same duration if steady state is reached in between. A typical pulse with transients is shown[1] in Fig. 1. Generally, the receiving system is gated, when an

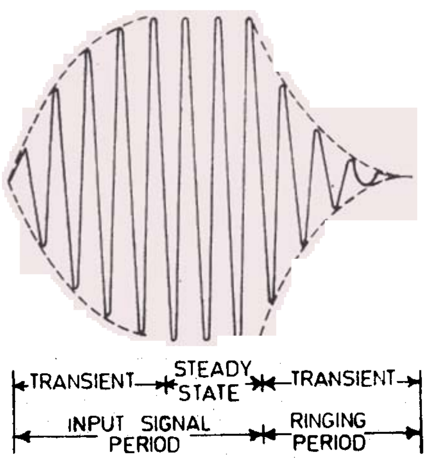


Figure 1. A typical pulse with transients in a system of $Q = 4$.

oscilloscope is not used as detector, to receive only the steady state portion of the transmitted signal. The signal waveforms at different stages of measurement with pulse technique are shown[2] in Fig. 2.

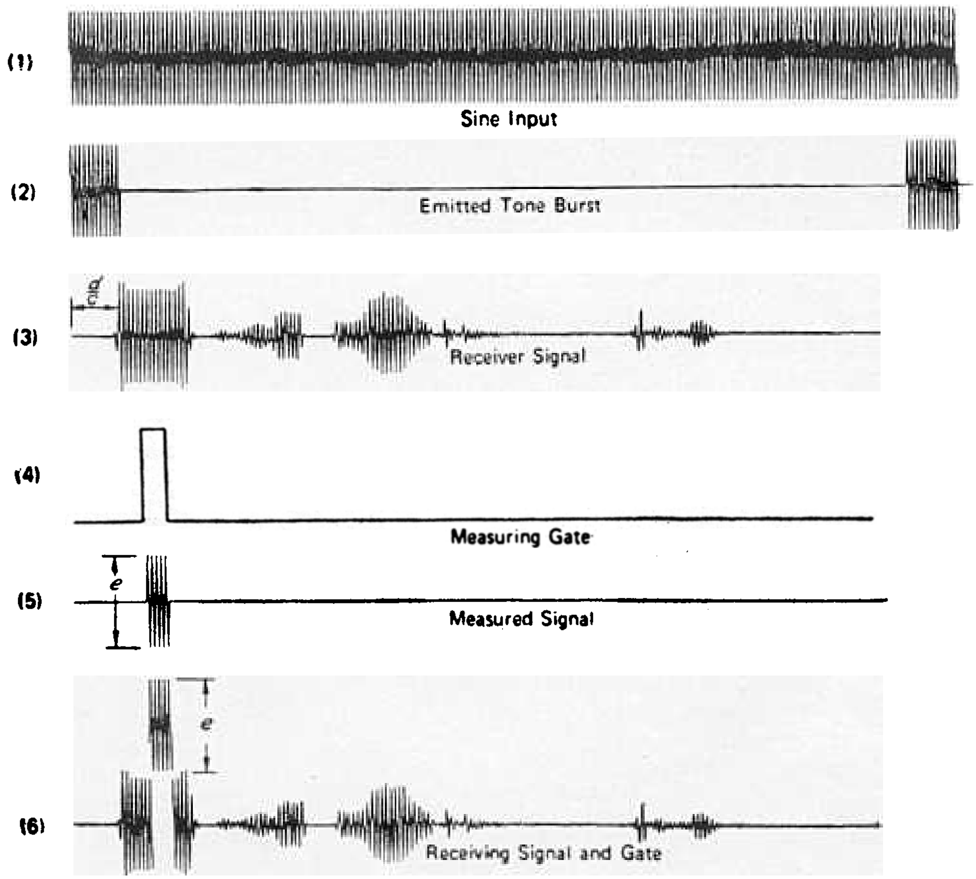


Figure 2. Signal waveforms at different stages of pulse technique.

The pulse technique for underwater acoustic calibration generally employs pulse repetition rates varying from 1 to 100 pps. The pulse widths vary from 0.1 ms to 10 ms depending upon frequency, path delay of undesired signals like boundary reflections etc.

The chief disadvantage of the pulse technique is that a pulse consists of a spectrum of frequencies and undistorted transmission of a pulse through the electro-acoustic measurement system thus requires a broad overall system response. The pulse technique has a definite low frequency limit though not high frequency limit.

Comparison Calibration in Small Closed Tanks

The acoustic pressure inside small closed tanks is the same at any point as long as the wavelength of sound in water is much greater than the largest dimension of the tank. This sound pressure is the actual applied pressure. When a hydrophone is calibrated in terms of the applied pressure, the calibration is called 'pressure sensitivity'. Pressure sensitivities are measured and used only when they are equal to the free-field sensitivities. This is satisfied for all hydrophones except moving coil ones and except for operation near resonance.

The author[3] has designed a portable low frequency hydrophone calibrator on the above principle with a reproducibility of better than $\pm$ 1 db in the frequency range of 500 Hz to 8000 Hz.

Near-Field Measurements

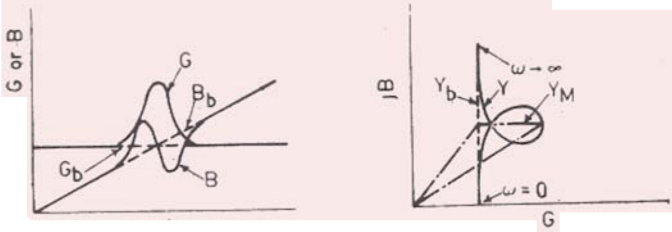
As the sonar technology is moving to lower and lower frequencies of operation to obtain underwater detection ranges and the transducer size becoming larger and larger, free-field far-field calibration calls for longer separation of projector and hydrophone extending even upto 30 meters. Near-field calibration techniques have essentially been developed in this context to save space by avoiding too unwieldly water volumes.

One such method, known as DRL Method, is based on Helmholtz principle. It requires measurement of magnitude and phase of pressure and pressure gradient. It envisages rotation of a calibrated probe hydrophone around a given large transducer in its near field over a closely covering integration surface. From the near-field pressure measurements, computations are carried-out to obtain far-field parameters.

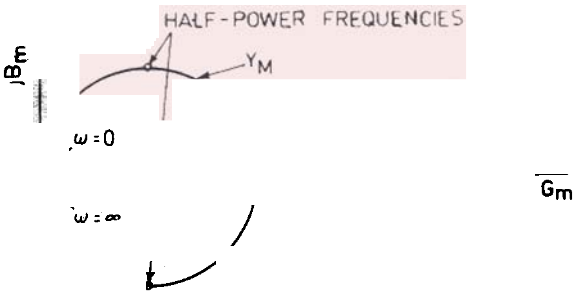
The other technipue, called Trott Array Method, is based on the concept that near-field and far-field sound pressures are related as spherical and plane wave reciprocity parameters. A binomial shaded line transducer is used for generating non-undulating sound pressure in the near-field. This Trott Array is used as projector. The test transducer and a calibrated standard hydrophone are used in the uniform plane progressive wave in the near-field of the array to measure receiving sensitivity by comparison calibration.

Impedance

The impedance is a very important parameter of an electro-acoustic transducer. It is an analytical tool for studying the performance. The motional impedance of a transducer consists of mechanical impedance (Z_m) due to vibrating part and acoustical or radiation impedance (Z_r) of the medium. The admittance plots of a piezo-electric



(b)



(c)

Figure 3. Admittance plots of a piezo-electric transducer

transducer are shown[1] in Fig. 3. The G vs J_B plot gives motional impedance and the diameter of the motional loop is inversely proportional to $X_m + Z_r$. These plots are also referred to as circle diagrams. If diameters of motional admittance circles in air (D_a) and in water (D_w) are kuown, the efficiency of a transducer is calculated from

$$\eta = \frac{D_w\,(D_a - D_w)}{G\,D_a}$$

Where G is the total conductance at resonance.

3. Design of Acoustic Tank

A water tank used to calibrate transducers is to be specially designed for the given requirements. The tank dimensions are a function of transducer separation (d), the Q of the transmitting system and the technique of measurement. The tank being a bounded medium, pulse technique is used to approach free-field conditions. The tanks can be of rectangular or circular cross-section and some of them are lined with sound absorbing wedges of a mixture of rubber and cork like corprene.

The required length of a tank can be calculated[4] from

$$L > d + \triangle d$$

and tank width and depth from

$$W > [(d \quad \Delta d)^2 - d^2]^{\frac{1}{2}}$$

Where d is additional path by which undesired acoustically reflected signals travel. Under these conditions, the absorbent lining is not required but may be useful in reducing reverberations and thus facilitating a higher pulse repetition rate for more rapid acquisition.

4. Facilities Available at Npol for Tests and Calibration Tank

The acoustic calibration tank at NPOL, Cochin is comparable in size with similar tanks anywhere in the world. It has a length of 12.25 M and a width of 7.65 M which are reduced to 10.70 M and 6.10 M at a depth of 6.10 M. This tapering in the tank walls is provided to eliminate specular reflection at tank walls. This combined with pulse technique makes it useful for most of the free-field measurements on underwater transducers. However, the tank walls are not fitted with any absorbing wedges. Dependtng upon the size of the transducer and lower and higher limits of frequency of operation, parameters like pulse width and transducer separation can be worked out. The NPOL tank can be used down to 4 or 3 KHz depending on the above parameters.

The tank has a facility of EOT crane for a safe working load of 3 tons for lifting any heavy transducers. It has also a facility to automatically plot directivity patterns of transducers with the help of a servo-controlled turntable. An air-conditioned instrument cabin is provided at one side. An automatic positioning system is under design to fix transducers in x, y, z directions to an accuracy of one centimeter. The proposed systsm will provide local control as well as remote control from instrument cabin. Also, all position parameters will be indicated in both the places.

Deep Water Facility

NPOL has established an underwater Acoustic Research Facility at Kulamavu in Kerala. This is situated in the western ghats at an altitude of about 610 M. above MSL. This provides a deep water facility for long lengths. All the measurements for which far-field criteria cannot be satisfied at NPOL calibration tank can be carried out at UARF, Kulamavu.

A water depth of 50 M to 125 M is available at UARF depending upon the season and location, An 80-ton barge is available at the facility for underwater measurements.

5. Conclusions

The underwater acoustic measurements have gained considerable significance for both military and non-military applications.

The calibration of underwater transducers needs special techniques for different conditions like far-field, near-field and closed environment as in small closed tanks.

Naval Physical & Oceanographic Laboratory, Cochin has facilities to carryout calibration of underwater sound transducers.

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