Low frequency Calibration of Hydrophones

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Introduction

Calibration of the frequency response of hydrophones is traditionally performed in a water filled acoustic tank using some kind of gated sine technique. However, there is a lower limiting frequency determined by amongst other the dimensions of the water tank and the sensor distance.
Consequently, quite a large acoustic tank is required in order to perform accurate calibration below a few kHz.
Unfortunately, very large acoustic tanks are expensive and seldom available and therefore - in some cases- the measured response is simply extrapolated to show a flat response in a wider frequency range than was actually measured; in other cases, a known nominal response is estimated as the best approximation of the low frequency response of every sensor.
To achieve individual and real hydrophone calibration at lower frequencies the calibration is sometimes done in a quiet lake or even at sea – in any case this results in new challenges such as more complicated logistics and influence from environmental noise and weather conditions.
The purpose of this poster and paper is to briefly explain the rationale behind low frequency calibration of hydrophones and present pros and cons of a number of different methods used for low frequency hydrophones calibration.
Examples of practical measurements are shown both results achieved with a commercially available system and results with a newly developed alternative more cost – effective laboratory setup

Limitations of an acoustic tank

The most common method for hydrophone frequency response calibration is free-field calibration by comparison in an acoustic tank (IEC 60656:2005 par. 9). Special precautions must be taken in order to reduce re-vibrations in the tank and free-field conditions are most commonly achieved by use of some kind of gating technique [1].

Modern systems often use selective FFT technique and offer equal or better results than obtained with a traditional analog gating system, but in some cases at the cost of limited frequency resolution and still quite a long calibration time.

In traditional electro acoustics, the TSR technique (Time Selective Response) is used with big success [2].

It would be tempting to use TSR technique for hydrophone calibration too, but so far, no hydrophone calibration system using this technique is commercially available.

In any case, for traditional sine burst technique the following 3 main criteria must be met when designing an acoustic tank for free-field hydrophone calibration with sine burst and gating technique.

Criterion 1.
The transducer must be in the far-field of the projector, for typical measuring hydrophones and a maximum frequency of 200 kHz this requires a minimum transducer separation of 0.67 meter, traditionally 1 meter – or more - is preferred.

Criterion 2.
The minimum burst length must be long enough that all transients have settled in order to have a stable signal available for the analyzer.
As a rule of thumb, it is considered that this criterion is met after a time corresponding to 2 full cycles of the sine signal for a typical system with a Q factor of two. Hence -for measurements to be possible down to f. inst. 2 kHz - the minimum burst duration is 1 ms (2 cycles a 0.5 ms).

Criterion 3.
The maximum burst length is limited by the requirement that the burst must be short enough to avoid interference with the reflexions and when this happens depends on the water tank dimension and hydrophone separation.

Below a sketch of a hypothetical acoustic tank with the dimensions 5 by 4 by 3 meter, the hydrophones are arranged in a triangular configuration, since this configuration is suitable not only for calibration by comparison but also for reciprocity calibration.

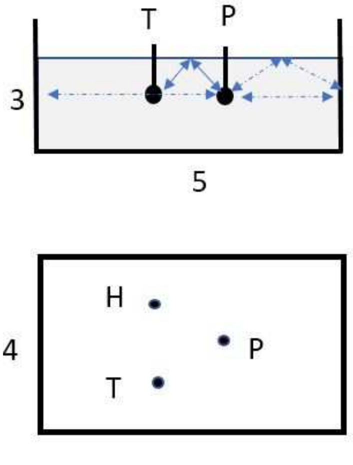

Figure 1: Cross section and top view of a typical acoustic, tank the lowest useable frequency depends on tank dimensions and sensor distance, some of the many potential reflexion paths are shown.

To comply with criterion 3 the pressure burst must be short enough to end before the first reflexion arrives at receiving hydrophone T (in case of comparison calibration).

These 3 criteria lead to a system of linear equations defining the maximum burst length depending on the physical dimensions of the water tank and transducer distances, this is shown graphically in fig. 2.

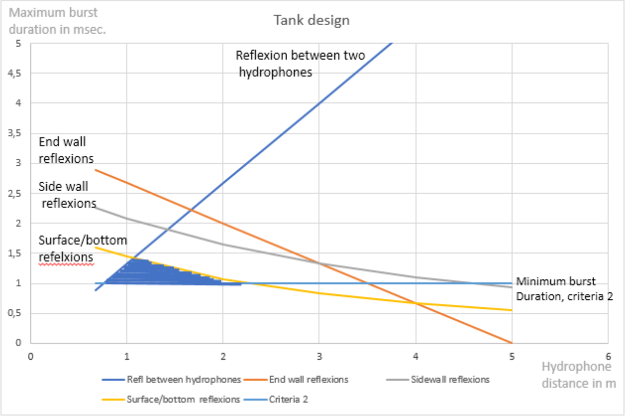

Figure 2: Maximum burst duration vs transducer distance for different parameters.

Combinations which meet all the three criteria are within the filled area in fig. 2.

The burst duration should be longer than 1 ms and with a hydrophone distance equal to 1 m the maximum allowable burst duration is approximately 1.3 ms.

In order to have sufficient signal to noise ratio, the burst should preferably contain minimum two full sine cycles - even at the lowest calibration frequency. This yields a (theoretically ideal) absolute minimum usable frequency equal to 1000/0.65 = 1538 Hz accordingly to criterion 3.

Further, in case a measuring hydrophone is used as projector the projected pressure level for a given voltage decreases with 12 dB/octave downwards and consequently the signal to noise may be too low at lower frequencies, or a more complicated two projector approach must be used.

In addition to the basic time window considerations explained here, there are other important parameters to consider, amongst them water tank material, wall damping, tank shape and structural vibrations – all of this is outside the scope of this paper.

Practical experiences have shown that it is quite difficult - and very expensive - to design and build an acoustic tank which allows good results below a few kHz. Consequently, manufacturers often will supply calibration charts with frequency response reaching down to 4 a 5 kHz only.

The need for low-frequency calibration

Being an acoustic sensor the receiving sensitivity of a hydrophone should be specified at 250 Hz; the sensitivity calibration can be done relatively easily with a (pistonphone type) so called hydrophone calibrator.

Some manufacturers seem to assume that the frequency response below a certain low frequency simply is a horizontal line, or it is assumed that the LF response of all transducers of the same type are identical and the response of a typical unit which has been measured outside the manufacturers acoustic tank is used as a best approximation for all units of that type.

From a quality assurance and traceability viewpoint this approach is far from ideal and in some cases not even acceptable.

To make things even worse, it is known that piezo electric sensors may suffer from a sudden change frequency response if the sensor is exposed to hard mechanical impact, something which relatively easy happens to a hydrophone.

Defects caused by mechanical impact to the sensor may result in low-frequency spikes as shown with arrows in figure 3.

(Graphs courtesy of Brüel & Kjær)

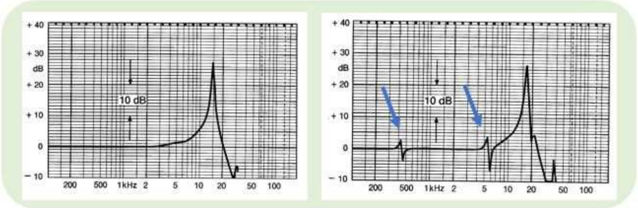

Figure 3: The left graph shows the response of an undamaged transducer (in this case an accelerometer) while the right is the response of a similar transducer which had been exposed to mechanical mistreatment, the arrows indicates two of the faulty response points.

Hydrophone low-frequency calibration

In recent years, there has been increasing interest in analysis of low frequency underwater noise and leading laboratories such as the National Laboratory for Ocean Technology (NIOT) in Chennai, India have been expanding their low frequency calibration capabilities. [3]

IEC 60565:2006 suggest a number of different methods amongst them the principle of a vibrating column (IEC 60565:2006 par. 14)

A variant of such a system has been supplied to amongst others NIOT.

In its most recent version the system consists of a thick walled Ø 300 mm aluminum tube, a 1 Giga Ohm input impedance hydrophone conditioning amplifier, power amplifier and a shaker to generate a pressure field in the water column. As presented in the IEC standard this system is an absolute system, but due to nodes in the water column the upper frequency for absolute calibration is in our case limited to 500 Hz or less; in order to compensate for this the system is operated in secondary mode using a reference hydrophone (B&K type 8104) which has been externally calibrated at low-frequencies.

The very high dynamic range (160 dB) of the actual FFT analyzer used allows correct measurement of the weak transducer signals even in the presence of strong resonance nodes and further the impact of resonance nodes is reduced by use of a low pass filtered random noise ("pink noise") excitation signal.

Figure 4 shows the water filled test vessel, the hydrophones are mounted at the end of the two vertical rods.

Figure 4: The test vessel is a thick walled Ø 300 mm aluminum tube with a vibrating bottom. The remaining instrumentation and the PC is in a nearby rack.

The test vessel features a floating bottom which is mechanically rigidly coupled to a powerful shaker, the static load of the vessel tube is carried by the floor and not by the shaker, in this way all shaker force can be used to produce an acoustic field in the water column.

Figures 5 and 6 shows typical measurements performed with such a system.

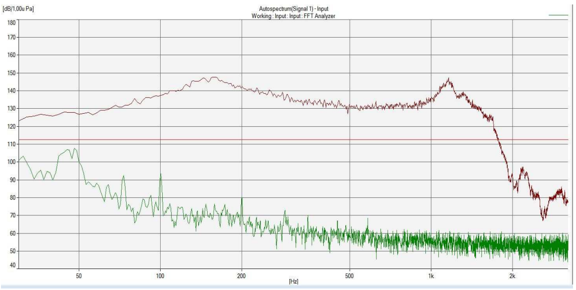

Figure 5: Upper curve shows the pressure in the water column vs frequency as measured by the reference channel (pink random noise excitation). The lower curve shows the system inherent noise which is mainly due to structural vibrations (HVAC system) and mains and its harmonics.

Some hydrophones have a build in pre-amplifier which cannot always be tested electrically; in such cases the LF calibration system will allow measurement of the complete frequency response of the hydrophone - including the pre-amplifier. An example of this is shown in figure 6.

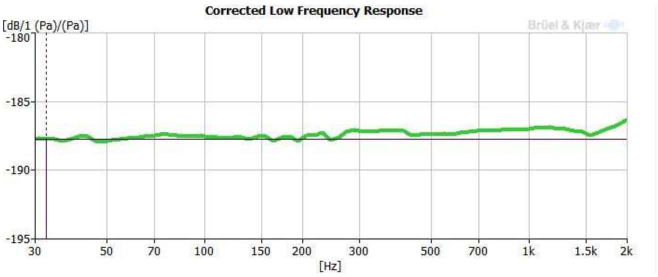

Figure 6: Measured LF response of a CATENAN Research hydrophone with a build in 20 dB amplifier.

Economy Solutions

The systems described so far are rather expensive and cannot be justified by the occasional user who is looking for a way to verify the low frequency performance and integrity of his transducers.

The economy solution presented here is suited for low volume easy verification of the low frequency response of hydrophones.

Such a solution will be affordable for a laboratory who may already have most of the equipment needed.

The idea is to use the fact that at low frequencies the diffuse field and free-field responses are identical and further that most hydrophones are omnidirectional at very low frequencies.

Therefore, if a sufficient high diffuse pressure field can be produced, a simple off the shelf FFT analyzer can be used for a verification (comparison with a known good unit).

Tests have been made using water basins with a volume as small as 50 liters and up to more than 200 l – results obtained with the smallest basin looks quite promising and are presented here.

The hydrophones can be mounted in line or in a triangular configuration something like 10 by 10 by 8 cm seems enough to obtain reasonable results at low frequencies. As always, the more precise the mounting reproducibility the better the results.

As always with hydrophones vibrations is a serious concern – measurements should be done in the basement if possible.

Another potential source of error is cross talk from the projector channel (typically 120 V_{pp}) to the input channels where the signal is in the uV range. Hence it is crucial to keep the projector cable separate from the signal cables

The figure below shows what is possible with respect to cross talk with an 8104 as projector driven by approximately 120 V_{pp} due to signal to noise ratio the lowest usable frequency is around 300 Hz.

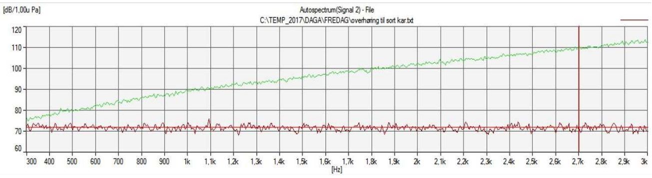

Figure 7: Received water pressure signal (upper curve) and cross talk signal (lower curve) vs frequency.

With a little care the verification results can be reproduced within a dB or so and the resolution is more than good enough to identify faults in a hydrophone under test including a build in amplifier.

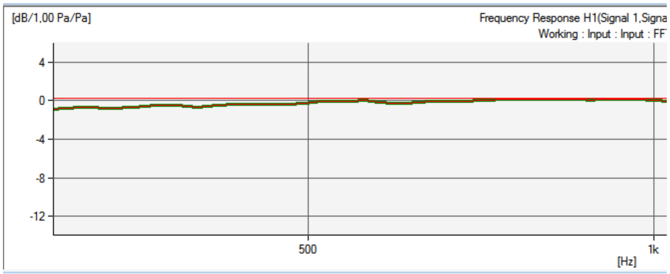

Figure 8: Measured LF response of a B&K type 8104 hydrophone.

In case of a cable damage or water penetration via the rubber piezo element encapsulation the leakage resistance causes a reduction in low- frequency sensitivity an example of this is shown in figure 9 below.

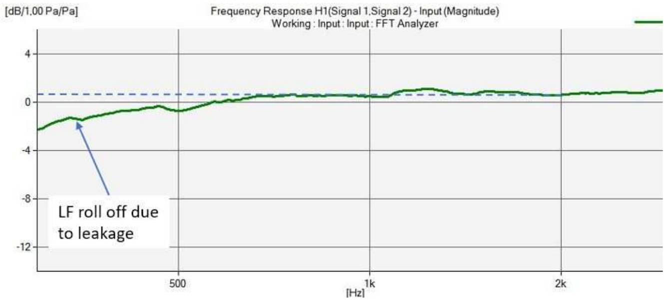

Figure 9: Measured frequency response of a hydrophone with excess LF roll off due to leakage in the hydrophone.

So far, all test results are based on a premium class multifunction analyzers (B&K LAN – XI modules).
Finally, tests were in order to see what can be achieved with a true economy solution; in this particular case a two plus two channel sound & vibration front-end SPECTRA DAQ200 which is based on a high-quality sound card a gain scalable preamplifier and its associated software.

As can be seen in figure 10 and 11 the results look very promising.

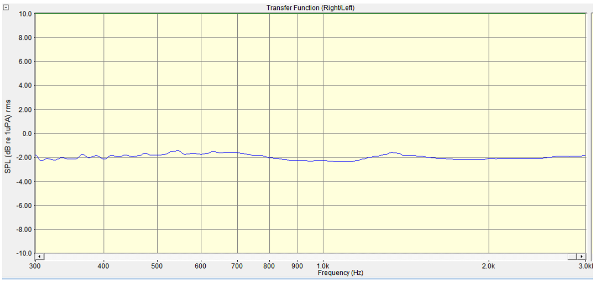

Figure 10: LF response of a B&K type 8104 as measured with an (uncalibrated) economy front-end.

Once more the LF response of the defective hydrophone was measured in order to see if the defect could be detected and indeed it could as can be seen in fig. 11 below.

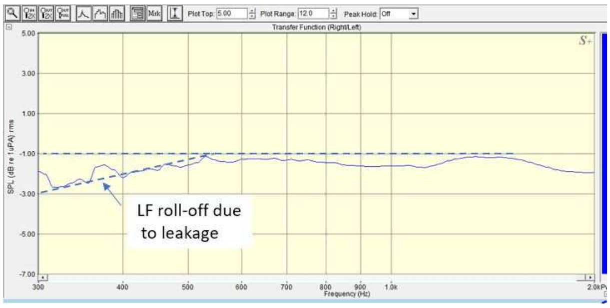
Plot Top: 5.00 Plot Range: 12.0 Peak Hold: Off

Figure 11: Measured response of a hydrophone with excess LF roll off due to leakage in the hydrophone.

Summary

Analysis of low frequency underwater noise is of increasing importance and so is LF calibration. In some cases, a full traceable calibration is required, but in many cases a reliable verification system is sufficient.
While a full hydrophone calibration system may costs far above 100 k Euro - not including the high cost and complexity of the acoustic tank – it seems that a low frequency verification set up is possible at a fraction of the cost of the more advanced calibration system.
Even a very basic front-end could be used with good results, which makes this approach a true economy solution.
Further work is planned with investigation of the pressure distribution in different test vessels and development of more user-friendly hydrophone mounting adaptors.

Literature

[1] BO 0157-11 Hydrophone Application Note,

Brüel & Kjær Sound & Vibration Measurement A/S

[2] Time Selective Response Measurements – Good Practices and Uncertainty. Erling Sandermann Olsen and Rémi Guastavino.

Technical Review No 1 – 2010 (bv 0062)

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[3] NIOT homepage,
URL: `http://www.niot.res.in/ATF/`