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A Study of the stability exhibited by hydrophones when exposed to variations in temperature and hydrostatic pressure

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Inter-laboratory testing is often undertaken between different National Metrology Institutes (NMIs) by comparison exercises with laboratories calibrating the same hydrophones. The expectation is that results will be within a small tolerance with each other, ensuring consistency among the different laboratories.

Hydrophone performance can vary when devices are exposed to different temperatures and hydrostatic pressures, and the degree of variance is different for each model. This can cause sensitivity discrepancies in the data being measured from different NMIs if the environmental conditions are not controlled.

NPL has a history of calibrating a variety of hydrophones, additionally NPL operates facilities where temperature and pressure can be controlled, resulting in an ability to calibrate hydrophones in different environmental conditions. In this paper the methodology for characterizing a hydrophone's response at different temperatures and pressure is explained. Additionally a study has been undertaken looking at the stability of commercially available hydrophones in order to determine which hydrophones are stable when transferred between different environments.

It was found that some hydrophones exhibit better stability against variations of temperature and pressure than others. Devices constructed with a simple sensor element that consists of a sphere of ceramic exhibit higher stability on average than more complex designs.

1. INTRODUCTION

For acoustic measurements to be meaningful, they must be traceable to common standards of measurement. For every hydrophone that is used to undertake a measurement, there needs to be an associated and up to date calibration that is traceable back to a primary standard. The calibration enables the data measured to be related to the sound pressure the hydrophone has been exposed to [2].

A hydrophone calibration undertaken in a laboratory will either be directly made using a primary standard method, or will be undertaken using a secondary method by comparison with a device that has been calibrated directly using a primary standard method [1]. The typical calibration will likely only be undertaken at a single temperature and hydrostatic pressure, and will be representative of the natural environmental conditions of the laboratory the device is being calibrated in. The device itself, however, may be used in vast range of environmental conditions, especially if used to measure sound in the ocean.

When exposed to different environmental conditions, such as temperature and depth (hydrostatic pressure), a hydrophone's sensitivity may change [2, 5]. If the calibration that is being relied upon to ensure the traceability of the measured data was not undertaken in conditions representative of those the device experiences during measurements in the field, then the calibration is not truly valid for those conditions. In order for the user to be able to trust a measurement from a hydrophone and evaluate the measurement uncertainty, we need to understand the sensitivity of that hydrophone, and additionally we need to understand how that sensitivity changes in different environmental conditions [5].

Any uncertainty about the sensitivity of a device, owing to varying environmental conditions, will have a negative effect on inter-laboratory testing, between different national metrology institutes, and also any field measurement where the device was not calibrated under the same conditions [5].

NPL has facilities that allow for temperature and hydrostatic pressure to be controlled during calibration, the acoustic pressure vessel (APV), and the Closed Chamber Reciprocity Coupler. These facilities have enabled a number of calibrations over the years that have measured the sensitivity of a wide range of hydrophones in different environmental conditions [6]. This paper reviews the change in sensitivity that can be seen in different devices that are exposed to different conditions, so that changes can be understood and accurately accounted for during measurements.

The work described here forms part of Infra-AUV, a joint project between European National Metrology Institutes and other relevant institutes which aims to develop new primary and secondary calibration capabilities for the fields of Acoustics, Underwater Acoustics and Vibration at low frequencies. Infra-AUV has received funding from the EMPIR programme (project 19ENV03), co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme. More information can be found on the project web-site at: <https://www.ptb.de/empir2020/infra-auv>

2. METHODOLOGY

A. MEASUREMENT FACILITIES

The APV consists of a 7.6 m long by 2.5 m diameter tank and is manufactured from several sections of firebox steel. The main cylindrical body of the vessel was constructed from two four inch thick plates. The two finished plates were welded together to achieve the specified vessel length. The vessel weighs 69,000 kg, this increases by approximately 32,000 kg when the water required to fill the chamber has been added. The interior of the chamber has a lining of acoustic absorbers that cover both ends of the APV. The absorbers are manufactured from a damp mixture of pine dust and cement and form a material known as Insulcrete. These wedges are suitable for their use in the APV because the acoustic performance does not vary significantly over the operational specification of the test chamber [2, 3, 4]. The layout and dimensions of the APV are shown in Figure 1.

The reciprocity coupler is a small metal chamber which can be filled with water, or any other liquid, which can then be pressurized and heated/cooled, similarly to the APV. The reciprocity coupler is considerably smaller however, the longest dimension of the test chamber is 166 mm. This small size of the coupler ensures a uniform pressure field – where the magnitude and phase of sound are spatially consistent [1] - within a particular frequency range in the chamber, which is a requirement of the calibration procedure for this facility.

In order to produce a uniform pressure field the longest dimension of the chamber needs to be significantly smaller than the wavelength of any given frequency generated within the chamber [1]. This means that above a certain frequency, wave modes will begin to form within the chamber, which makes calibration more difficult for this facility without added corrections. Other similar couplers are available at NPL that feature air-filled chambers, however the reciprocity coupler is water-filled, enabling control of the temperature and pressure within the coupler, and allowing measurements at higher frequencies than would be possible in air. This is because the speed of sound in water is higher, and therefore the wavelengths of frequencies are comparatively increased, therefore creating a wider frequency range at which a uniform pressure field is possible.

The reciprocity coupler is currently in the process of having the software and hardware modernized as a part of the EMPIR funded Infra-AUV project.

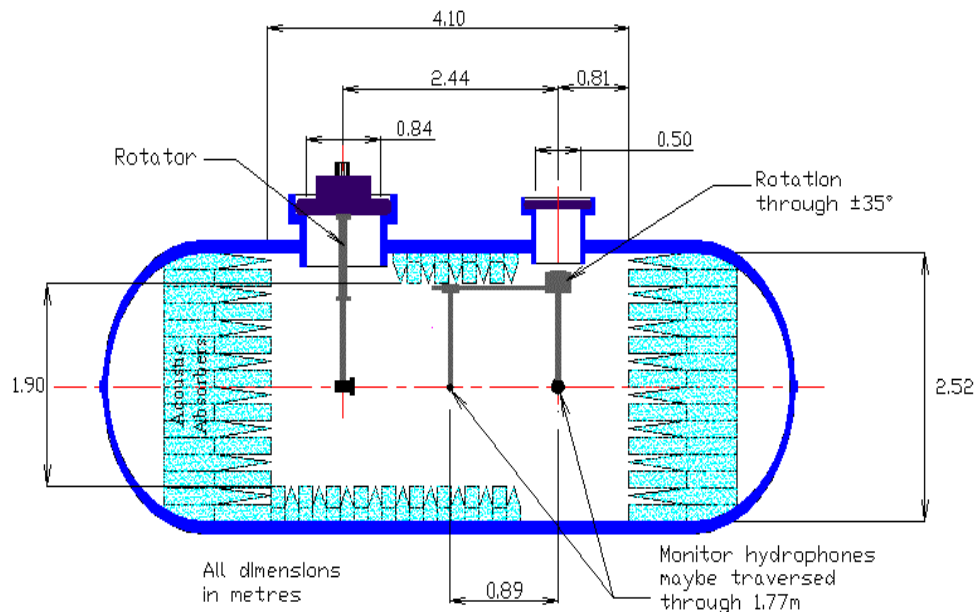


Figure 1. Schematic of the Acoustic Pressure Vessel (APV)

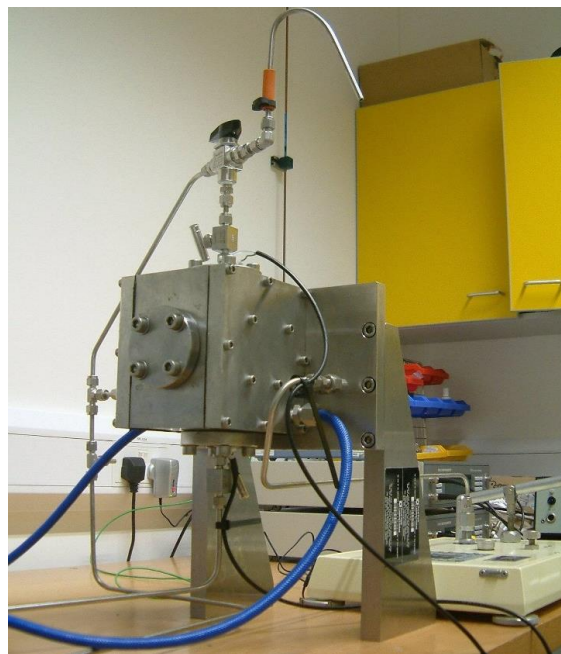


Figure 2. Picture of the Closed Chamber Reciprocity Coupler

Both the APV and the Closed Chamber Reciprocity Coupler have the capability to conduct measurements between ambient pressure, and up to 7 MPa, additionally the temperature of the water can be controlled within the chambers between 2 °C to 35 °C [1, 2].

B. MEASUREMENT METHODOLOGY

The free-field receive sensitivity of all hydrophones in different environmental conditions was determined by the method of three-transducer spherical wave reciprocity in conformance with BS EN IEC 60565-1. The procedure requires that three hydrophones be operated in pairs, with one transmitting and one receiving [3].

In the APV gated tone bursts are used in order to avoid interference from acoustic reflections. In the reciprocity coupler a continuous sound field is generated creating a uniform pressure field. For calibrations using the coupler reciprocity method, the measurements were made according to BS EN IEC 60565-2.

For measurements taken in the APV, the temperature is set to change gradually overnight and maintained for calibrations during the day, whereas the reciprocity coupler's water temperature may be heated and cooled more rapidly. When changing the hydrostatic pressure inside the APV or the reciprocity coupler, the hydrophones are left for 15 minutes to acclimatize to the new pressure before measurements begin.

Prior to undertaking sensitivity measurements, the electrical impedance of the hydrophones and any attached cables is measured. This allows for a correction to be applied to the end results that accounts for the length and resistance of any cable attached to the hydrophone at the time of testing.

The stability of a hydrophone is determined by measuring the sensitivity of that device at multiple temperatures and pressures. It is important to also measure at a range of pressures for each temperature, since a hydrophone's pressure stability can also vary at different temperatures. Plotting all the results can make the stability of a device easily visually comparable against another, but it is also possible to generate a set of coefficients that mathematically define the stability of a hydrophone, and can be applied to the associated hydrophone in order to correct measurements undertaken in environmental conditions that a different to those the device was calibrated in.

It is possible to get a satisfactory indication of a device's stability by undertaking electrical impedance measurements only at different temperatures and hydrostatic pressures. While this will not give information on the sensitivity of a device directly and cannot be used to calculate a set of coefficients, the stability (or lack of it) is still evident from the impedance measurements. Additionally, it reduces the time investment and the necessary number of hydrophones to the device under test only [3, 4]. Figure 3 shows the variation in sensitivity of a Reson TC4013 at different temperatures and how this is reflected in the electrical impedance plot.

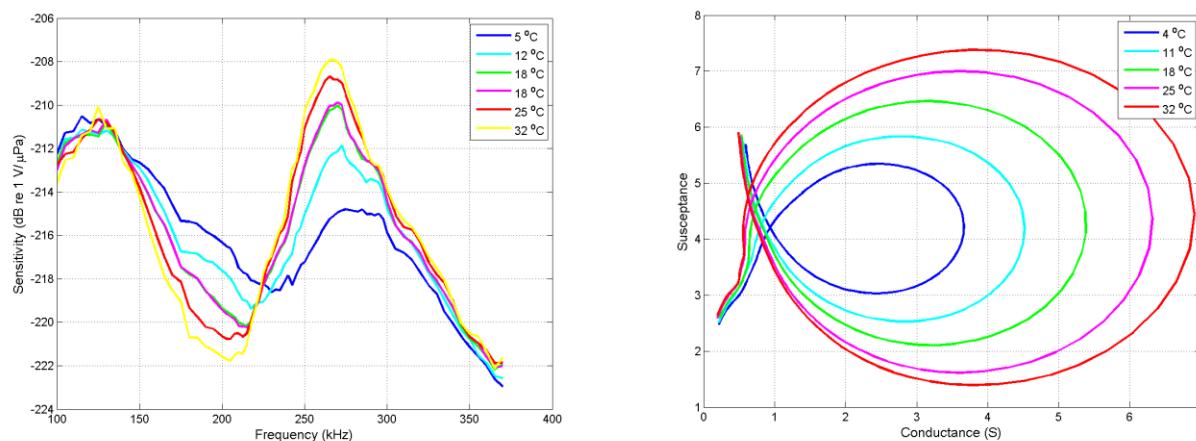


Figure 3. The variation in sensitivity (left) and electrical impedance (right) of a Reson TC4013 at different temperatures

3. RESULTS

The hydrophones whose performance have been studied for review are listed in Table 1.

Table 1. A list of all hydrophones analyzed for this study

Hydrophone make and model	Temperature range measured (degrees Celsius)	Pressure range measured (MPa – absolute pressure)
B&K 8103	5 - 32	0.1 – 4.0
B&K 8104	5 – 32	0.1 – 6.8
B&K 8105	10 – 30	0.1 – 6.8
ITC 1001	4 – 32	0.1 – 6.8
ITC 1032	4 – 32	0.1 – 6.8
ITC 1042	4 – 28	0.1 – 6.0
ITC 1089C	4 – 32	0.1 – 6.8
ITC 1089D	4 – 32	0.1 – 6.8
Reson TC4014	4 – 32	0.1 – 6.8
Reson TC4033	4 – 32	0.1 – 6.8
Reson TC4034	4 – 32	0.1 – 6.8
USRD F30	4 – 28	0.1 – 6.0
USRD H52	4 – 28	0.1 – 6.8

The performance of all devices listed in Table 1 have been measured in the APV, with the B&K 8104 and the Reson TC4033 having supplemental measurements undertaken in the reciprocity coupler.

All graphs for the devices listed in Table 1 can be found in an associated report generated as a part of the Infra-AUV project (6). Figures 4 and 5 show the measured sensitivities for a B&K 8104 and an ITC 1001. These devices have been chosen as a representation of hydrophones with low and high stability.

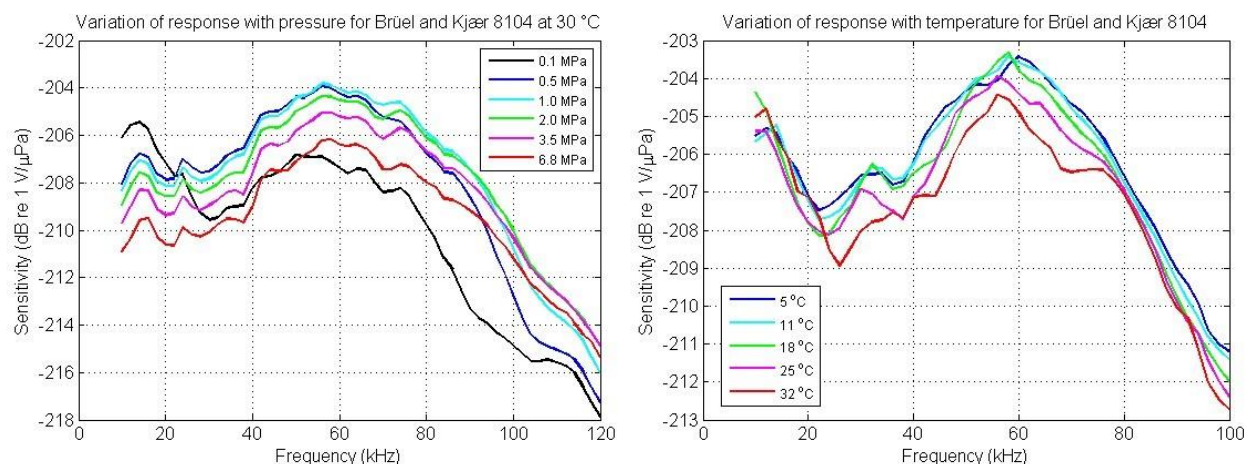


Figure 4. Variation in sensitivity of a B&K 8104 when exposed to different hydrostatic pressures (left) and temperatures (right) [6]

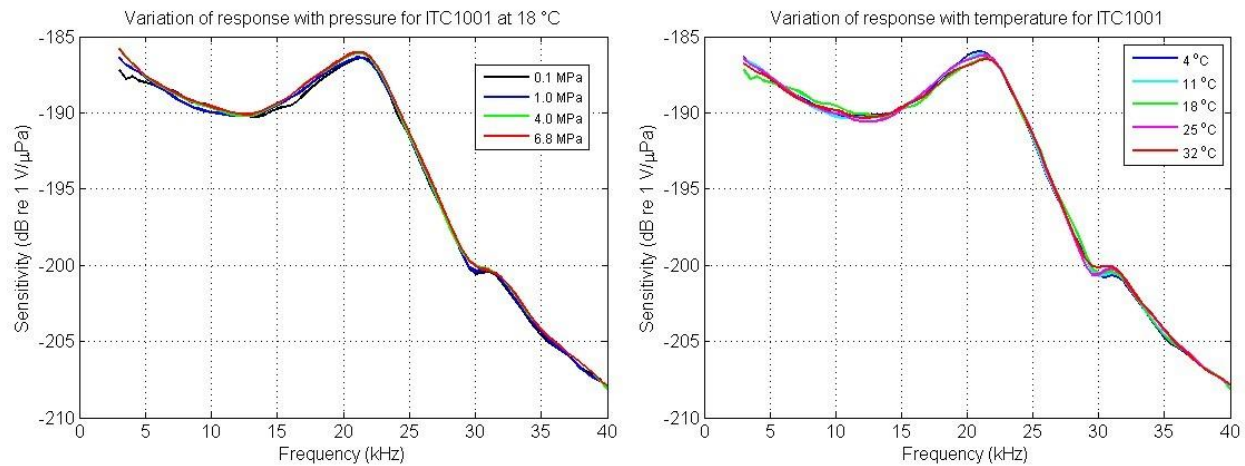


Figure 4. Variation in sensitivity of an ITC 1001 when exposed to different hydrostatic pressures (left) and temperatures (right) [6]

As can be seen from Figures 4 and 5 the two hydrophones have been exposed to a nearly identical range of temperatures and hydrostatic pressures and the B&K 8104 exhibits significantly more variation in its sensitivity. Also visible in Figure 4 is the fact that the sensitivity change between the different hydrostatic pressures is not linear. For example the difference in sensitivity between 0.1 MPa and 0.5 MPa is much greater than between 0.5 MPa and 1.0 MPa or even between 1.0 MPa and 6.8 MPa. It is also notable from looking at figures 3, 4 and 5 that the most dramatic change in sensitivity occurs at the frequencies close to the resonance frequency of the device.

A transducer with a more sophisticated element design can offer advantages in providing a more damped and “flatter” frequency response, but can also suffer from greater instability in its sensitivity when exposed to variations in temperature and depth (hydrostatic pressure). This may be due to the many different components making up the element reacting differently to the changing hydrostatic pressures and temperatures, whereas a simple design of transducer element (for example, made of a single sphere of piezoceramic material) suffers less from this problem.

4. CONCLUSION

Exposure to different environmental conditions can significantly alter a hydrophone’s sensitivity, although the amount varies between devices [1, 2, 5]. This variation is important to understand because if a hydrophone is being used in an environment with significantly different temperatures and hydrostatic pressures than was used for its calibration, then the results measured with that hydrophone could be inaccurate.

It is possible to generate a set of coefficients for a hydrophone that allow the user to apply corrections to their sensitivities for the different temperatures and hydrostatic pressures that the device has been exposed to. Alternatively, for a hydrophone that varies significantly, it could be calibrated under the conditions that the hydrophone is expected to experience when used for measurements in the field. Use of a hydrophone where the sensitivity does not vary significantly over a wide range of temperatures and pressures would reduce the uncertainties when undertaking the measurements in the field since any corrections will inevitably add extra uncertainty.

NPL has undertaken a number of calibrations of hydrophones at different temperatures and hydrostatic pressures that allows a study of the stability of these different devices. These calibrations have been undertaken in both our Acoustic Pressure Vessel (APV) and our Closed Chamber Reciprocity Coupler. These calibrations have been undertaken by the method of three-transducer spherical wave reciprocity in conformance with BS EN IEC 60565-1 and BS EN IEC 60565-2

It is also noted that in-lieu of a full set of calibrations in different environmental conditions, electrical impedance measurements can instead be undertaken to assess stability. This will give an indication of the stability of a device, without requiring the time investment for a full calibration [3, 4].

From reviewing the results of the calibrations, it is evident that more complex transducer element designs have a greater tendency to have their sensitivity vary when exposed to different measurement environments. In

comparison, less complex transducer designs are generally more stable. Stability, however, is not the only factor to be considered when deciding what hydrophone to use for any given measurement, and although one hydrophone may be less environmentally stable than another, there are other performance characteristics of a hydrophone that are also equally important such as size, frequency range of use, directivity and frequency response variation.

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REFERENCES

- ¹Ablitt, J., Beamiss, G. A., Robinson, S. P., & Hayman, G. (2006). Hydrophone performance variation with water temperature and depth. *Proc. UDT Europe, Hamburg, 2006*.
- ²Beamiss, G. A., Hayman, G., & Robinson, S. P. (2002). Variation in free-field response characteristics of hydrophones with temperature and depth. *Proceedings of the IOA Spring Conference, vol24*,.
- ³Beamiss, G. A., Robinson, S. P., Hayman, G., & Esward, T. J. (2002). Determination of the Variation in Free-field Hydrophone Response with Temperature and Depth. *Proceedings of the Sixth European Conference on Underwater Acoustics, ECUA2002, Gdansk, p 635-640, June 2002*
- ⁴Beamiss, G. A., Robinson, S. P., Hayman, G., & Esward, T. J. (2002). Determination of the Variation in Free-field Hydrophone Response with Temperature and Depth. *Acta Acustica United With Acustica*, 799-802.
- ⁵Van Buren, A. L., Drake, R. M., & Paolero, A. E. (1999). Temperature dependence of the sensitivity of hydrophone standards used in international comparisons. *Metrologia*, 281-285.
- ⁶Ford, B, Robinson S.P. and Ablitt J. Report on the stability of current hydrophones at varying temperatures and hydrostatic pressures. Report of project Infra-AUV, 2021. Available from project web-site: <https://www.ptb.de/empir2020/infra-auv>