

LOW FREQUENCY HYDROPHONE CALIBRATION WITH A LASER INTERFEROMETER

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Abstract: *This paper describes experimental work that aims to provide a new method for primary pressure calibration of hydrophones in the frequency range from 20 Hz to 250 Hz. A measurement setup with a laser interferometer has been used to realise the acoustic pascal in an enclosed chamber. An optically flat piston is driven harmonically in a chamber containing both a fluid and a hydrophone to be tested. The absolute displacement of the piston is determined by fringe counting on a Michaelson interferometer. The thermodynamic properties of the fluid are used to calculate the absolute acoustic pressure that the hydrophone is exposed to from the volume change in the chamber. An advantage of such primary calibration is its traceability to primary standards of length via the wavelength of laser light. Some provisional hydrophone calibration results are shown and a discussion provided on potential sources of uncertainty. This method offers a possible primary standard for the low frequency range where regulation mandates the monitoring of absolute noise levels in the ocean, and where many sound sources of concern emit the most of their energy.*

Keywords: *acoustic calibration, hydrophone sensitivity, pistonphone, low frequency, one third octave bands, ocean noise*

AIM

The aim of this experimental work is to provide a new primary acoustic pressure calibration standard at low frequency for hydrophones. The motivation is to provide traceability for noise recordings with a focus on evaluating the marine environment, particularly the impact of low frequency anthropogenic noise as identified in the Marine Strategy Framework Directive (MSFD)[1]. The MSFD identifies 63 and 125 Hz bands as a means to capture annual trends in noise[2]. Primary calibration and traceability will therefore be an important aspect of marine noise measurement in the future and is pursued in this paper. This will be particularly important where comparisons of underwater noise are to be made over several years or even decades.

METHOD

A pistonphone is an acoustic calibration device that generates pressure by driving a circular piston into a closed volume of fluid. Knowledge of the thermodynamic properties of the fluid in the chamber can be used to relate a change in volume to a change in pressure. The laser pistonphone uses a Michelson interferometer to measure the displacement of the piston. The laser pistonphone is one of a number of low frequency hydrophone calibration techniques identified in the International Electrotechnical Commission standard for hydrophones[3].

The National Physical Laboratory (NPL) has established a method for absolute calibration of hydrophones using a laser pistonphone. This method of hydrophone calibration can in principle be applied from a few hertz to several hundred hertz [4, 5]. In this pistonphone, the sound pressure is generated in a small closed air-filled chamber by driving a piston with a toneburst signal. The acoustic pressure p in the chamber can be calculated from:

$$p = \frac{\gamma p_s \Delta V}{V}$$

where V is the volume of the chamber, ΔV is the volume change caused by displacement of the piston, p_s is the static pressure and γ is the ratio of specific heats for the fluid. In this case the fluid used is air, at approximately room temperature.

ΔV is calculated from the surface area of the circular piston and by counting fringes on a Michelson interferometer as a means to obtain piston displacement. The surface of the piston is made optically flat to reflect the laser light.

The piston is driven into the chamber with a ten-cycle toneburst. The static pressure is taken as one standard atmosphere (101.325 kPa), however, barometric pressure could potentially be used to obtain a more accurate result at the time of the measurement. Unlike coupler reciprocity, this primary calibration method has its traceability to the primary standards of length via the wavelength of laser light.

RESULTS

This section describes measurement results for the calibration of a small hydrophone. A comparison is made between the original manufacturer's calibration at a single frequency and the range of calibration frequencies achieved in the test. The centre-frequencies of tonebursts were set to the (base 10) one-third octave intervals in the range from 20 to 500 Hz. The piston

displacement was observed through a small glass window in the chamber. Fig. 1 shows the interferometer set up with the laser path annotated with the chamber removed. Fig. 2 shows the front face of the piston and Fig. 3 shows the chamber fitted to the baffle with a socket for the hydrophone.

The photodiode signal from the interferometer was captured concurrently with the hydrophone signal on the same oscilloscope. A high sampling rate was needed to sample sufficiently the high bandwidth of the photodiode signal, while a significant amount of oscilloscope memory was needed to capture the full duration of the low frequency tonebursts. The shaker has low impedance at approximately 1.5Ω at 20 Hz. This leads to a minimal drive voltage needed for the piston to cross many fringes. Fig. 4 shows the photodiode fringe signal with the drive signal in continuous-wave. The drive signal is within 400 mV peak to peak at 300 Hz, which here generates 43 fringes of displacement on the photodiode signal.

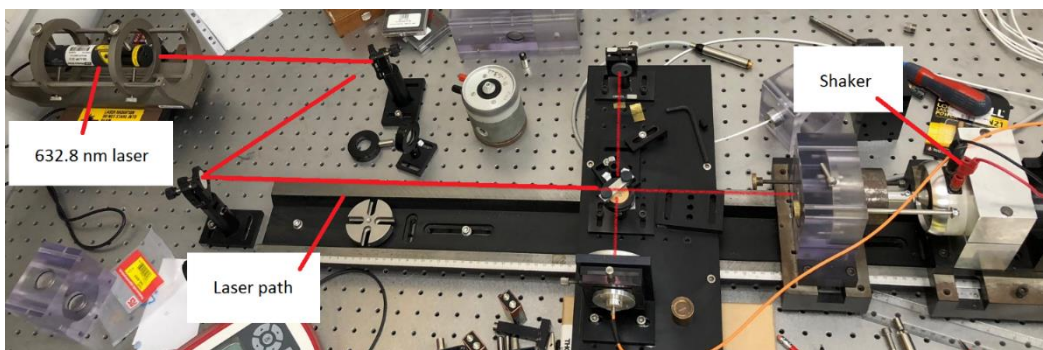


Fig. 1 Bench set up showing laser, laser path and shaker

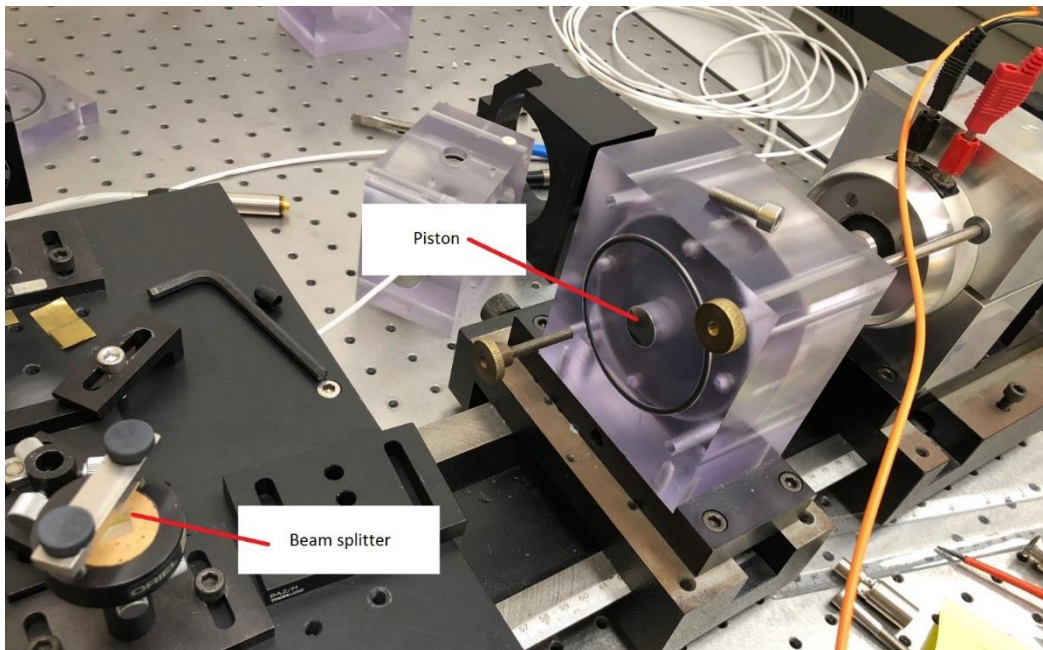


Fig. 2 Disassembled chamber showing front-face of the piston and beam splitter

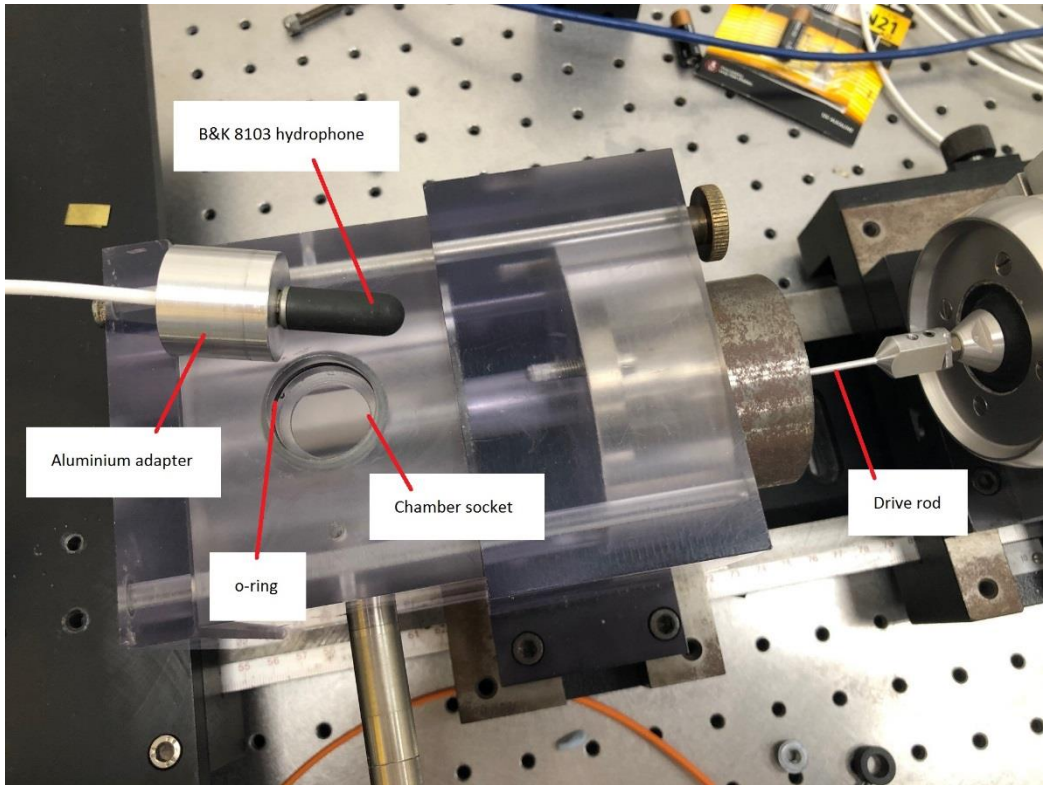


Fig. 3 Chamber showing hydrophone, fitting assembly and piston drive-rod

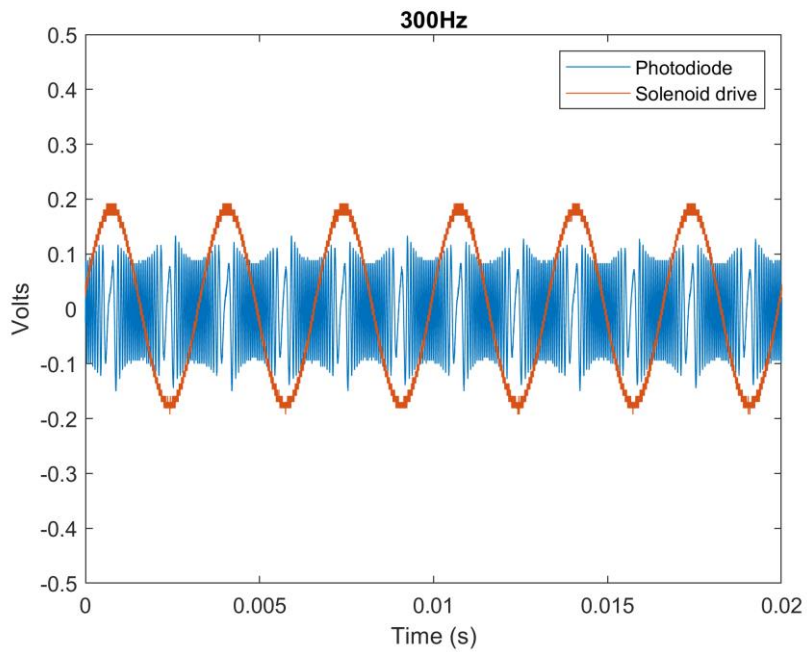


Fig. 4 Shaker drive voltage and interferometer signal in continuous-wave, showing the chirp-like nature of the photodiode signal

The hydrophone and photodiode signals are captured for a ten-cycle toneburst at 20 Hz. At low frequency the toneburst signal is replicated consistently on the hydrophone as seen in Fig. 5 and the photodiode registers many fringes. A spectrogram of the photodiode signal reveals the chirp-like nature of the signal in Fig. 6.

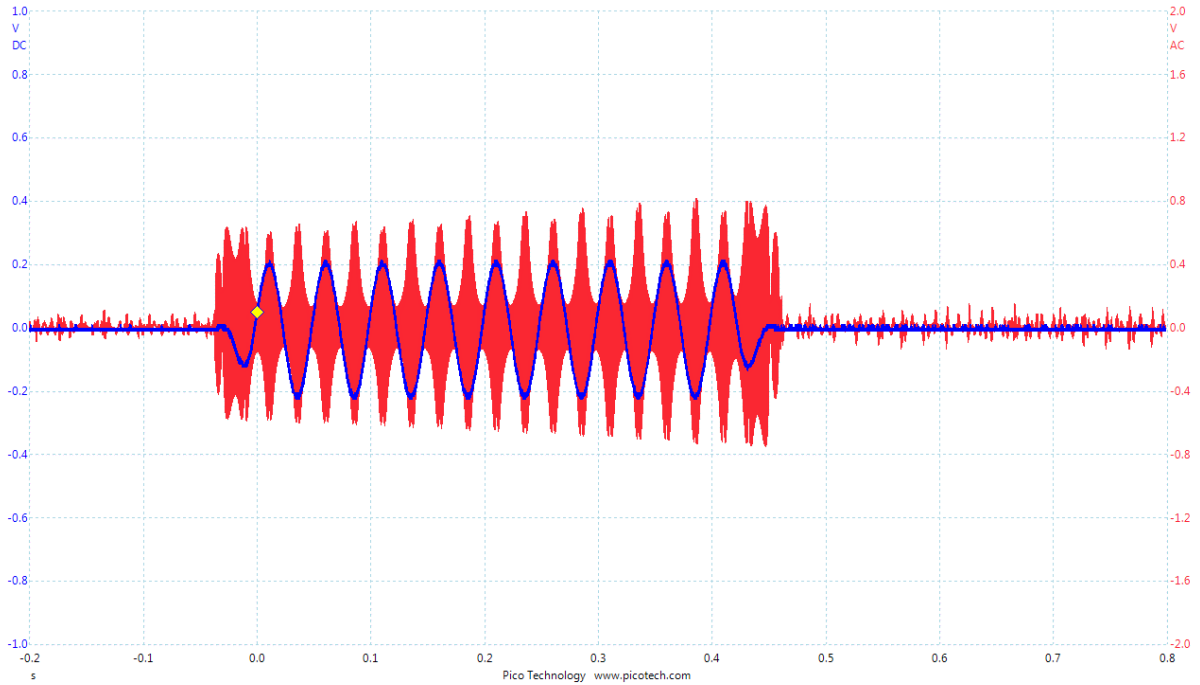


Fig. 5 Hydrophone (blue) and photodiode signal (red) for a ten-cycle 20 Hz drive signal

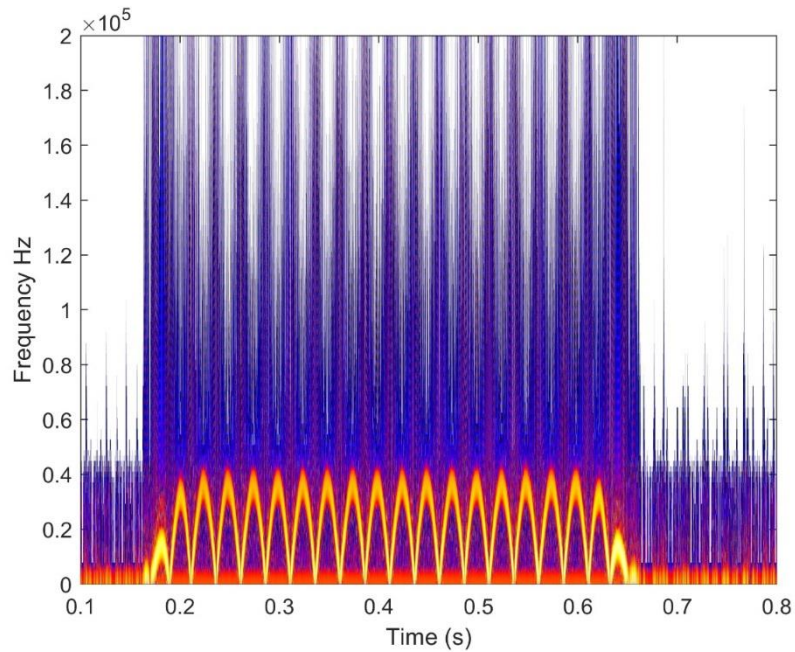


Fig. 6 Spectrogram of photodiode signal showing 40 kHz bandwidth required

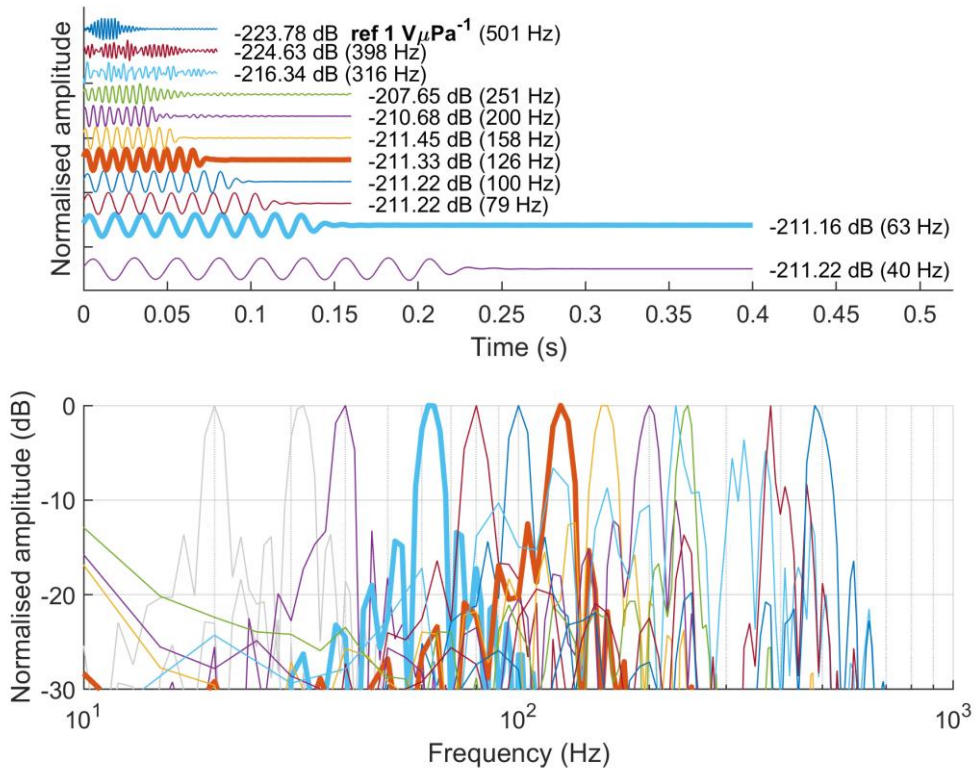


Fig. 7 Hydrophone signals and spectra. Principal MSFD frequencies shown in bold

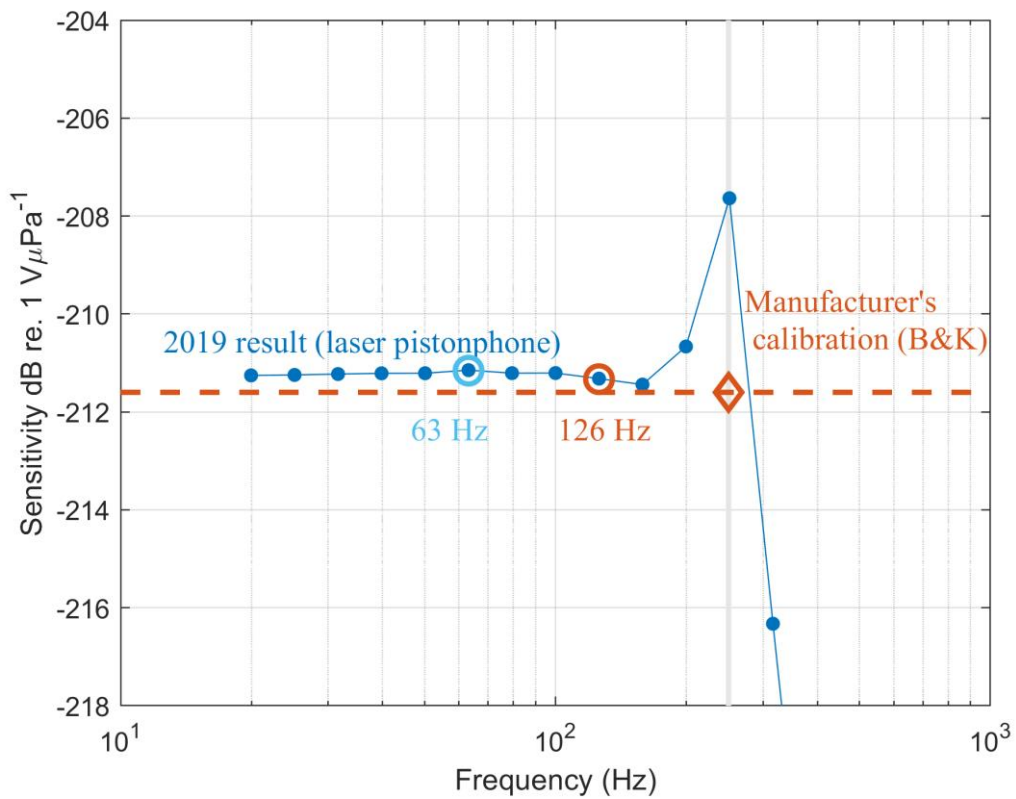


Fig. 8 Sensitivity compared with manufacturer's calibration at 250 Hz (type B&K 8103)

DISCUSSION

Fig. 7 (top) displays a sequence of hydrophone signals from tonebursts at different frequency. The corresponding hydrophone sensitivity is annotated on the graph in dB re. 1V/ μ Pa. The pressure in the chamber is derived from both the laser interferometer and the open-circuit voltage signal on the hydrophone cable were used to calculate the sensitivity. As can be seen the toneburst is well replicated in the signals up to 158 Hz. The spectra for these time traces are given in Fig. 7 (bottom). Above 158 Hz the hydrophone measurement is affected by resonances in the chamber, the drive system and bench. The results are summarised in Fig. 8 and tabulated below. Table 1 indicates the reliable range of the measurement and highlights the 63 and 125 Hz frequencies in bold. These correspond to the bold lines in the signals and spectra plotted in Fig. 8. Opportunities identified to improve the measurement include updating the shaker to an actuator of higher blocking force and finding a means to adjust the volume of the chamber. Furthermore, an interferometer with sub-fringe resolution would be an advantage.

Frequency (Hz)	Sensitivity dB ref 1V/ μ Pa
20.0	-211.3
25.1	-211.3
31.6	-211.2
39.8	-211.2
50.1	-211.2
63.1	-211.2
79.4	-211.2
100.0	-211.2
125.9	-211.3
158.5	-211.5
199.5	-210.7
251.2	-207.6
316.2	-216.3

Table 1 Measured hydrophone sensitivities with principal MSFD frequencies in **bold** and unreliable results in grey

SOURCES OF UNCERTAINTY

These laser pistonphone measurements rely on several physical measurements and assumptions. In these calculations it is assumed there is no heat conduction, that is to say that compression and rarefaction are adiabatic. It is also assumed that there is no leakage of air from the chamber around the piston. In practice both heat flow and air leakage would limit the lower bound in frequency. An approach to correcting for these effects can be found in detail in Barham and Goldsmith[4]. Contributors to uncertainty are listed below:

- i. Atmospheric pressure (p_s)

- ii. Ratio of specific heats (γ), taken as 1.4
- iii. Diameter of the piston
- iv. Optical wavelength
- v. Integer fringe counting (and frequency)
- vi. Photodiode signal to noise
- vii. Hydrophone preamplifier gain
- viii. Cavity volume (V)
- ix. Distortion in the harmonic drive signal
- x. Isothermal behaviour (heat flow in the chamber)
- xi. Pressure leakage
- xii. Vibration sensitivity
- xiii. Voltage measurement uncertainty
- xiv. Ambient temperature and humidity

CONCLUSION

The laser pistonphone is a valid and effective means for low frequency calibration of hydrophones. Through this work the technique has been adapted from an application of microphone calibration to hydrophones. The chamber used in these measurements has demonstrated the technique in the range from 20 to 158 Hz. This primary calibration technique is one suitable means to satisfy the requirement for traceability in the calibration of hydrophones and recorders used in monitoring annual trends in the 63 and 125 Hz bands, as identified in the MSFD Guidance[2].

ACKNOWLEDGEMENTS

The work described here was partly-funded by UNAC-LOW. UNAC-LOW is a EURAMET EMPIR project (project 15RPT02) aimed at an integrated, cost effective and internationally competitive measurement infrastructure for Europe. The work was also funded by the National Metrology Programme of the UK department of Business, Energy and Industrial Strategy.

REFERENCES

- [1] **Directive 2008/56/EC**, Establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive), Official Journal of the European Union, 2008.
- [2] **Van der Graaf AJ, Ainslie MA, André M, Brensing K, Dalen J, Dekeling RPA, Robinson S, Tasker ML, Thomsen F, Werner S**, Guidance for 2012 reporting under the Marine Strategy Framework Directive, 5.3.3 Underwater Noise (8B03), 2012
- [3] **IEC 60565-2006**, Underwater acoustics – Hydrophones – Calibration in the frequency range 0.01 Hz to 1 MHz, International Electrotechnical Commission, Geneva, Switzerland, 2006.
- [4] **Barham, R.G and Goldsmith, M.J.**, The application of the NPL laser pistonphone to the international comparison of measurement microphones, *Metrologia* **44**, 210–6, 2007.
- [5] **Wen He, Longbiao He, Fan Zhang, Zuochao Rong and Shushi Jia**, A dedicated pistonphone for absolute calibration of infrasound sensors at very low frequencies, *Meas. Sci. Technol.* **27**, 025018 (11pp), 2016.