A comparison of hydrophone calibration by free-field reciprocity and by optical interferometry in the frequency range 200 kHz to 1 MHz.

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Abstract: NPL has established two primary standard methods for the free-field calibration of hydrophones. In the frequency range 500 kHz to 20 MHz, the primary standard is realised using optical interferometry; in the range from 2 kHz to 500 kHz, it is realised by the method of three-transducer spherical-wave reciprocity. Although the ranges of the primary standards are defined as above, both methods can be used in the frequency range 200 kHz to 1 MHz, enabling a comparison to be undertaken between these two independent methods. The comparison was made by calibrating reference hydrophones using both methods and comparing the results. In general, the results agree to within ±0.4 dB or better, well within the combined uncertainties of the methods.

INTRODUCTION

In metrology, the primary standard is the most accurate implementation of an absolute calibration method, usually traceable as directly as possible to the primary standard base units. As the national standards laboratory for the UK, NPL has established two primary standard methods for the free-field calibration of hydrophones. In the frequency range 500 kHz to 20 MHz, the primary standard is realised using optical interferometry; in the range from 2 kHz to 500 kHz, it is realised by the method of three-transducer spherical-wave reciprocity. One of the most important methods of validating a primary standard is to compare with another independent absolute calibration method, preferably one based on a different physical principle (and therefore with few common sources of uncertainty). Although the ranges of the two primary standards are defined as above, both methods can be used in the frequency range 200 kHz to 1 MHz, enabling a comparison to be undertaken between these two independent methods.

METHODS

The primary calibration of hydrophones for frequencies greater than 500 kHz is achieved using the NPL laser interferometer (1). In this method, an ultrasonic transducer produces an acoustic field which is detected by a thin plastic membrane (the pellicle) which is 5 μm thick and coated on one side with 25 nm of gold. The pellicle reflects the optical beam but is effectively transparent to the acoustic beam so that it follows the motion of the wave. The displacement of the pellicle is determined using a specially-designed Michelson interferometer and the acoustic pressure in the field is calculated from the measured displacement. The hydrophone is then substituted for the pellicle with the acoustic centre placed at the same point in the field that has been interrogated by the interferometer. The calibration is performed by measuring the hydrophone output voltage corresponding to the known acoustic pressure. Advantages of this method are its direct traceability to primary standards of length and its insensitivity to the properties of the ultrasonic field generated by the transducer. Using the laser interferometer, a reference hydrophone can be calibrated in the frequency range 200 kHz to 1 MHz with typical overall uncertainties (95% confidence level) of between ±0.3 and ±0.5 dB.

The primary method of calibrating hydrophones in the frequency range 2 kHz to 500 kHz is three-transducer spherical-wave reciprocity (2-3). This method requires the use of three hydrophones, at least one of which must be a reciprocal transducer; that is, its transmitting and receiving sensitivities are related by a constant factor. The hydrophones are paired off in three measurement stages, at each of which one device is used as a transmitter and the other as a receiver. For each pair of hydrophones, a measurement is made of the ratio of the voltage across the terminals of the receiving device to the current driving the transmitting device. Using the reciprocity principle as applied to the reciprocal hydrophone, the sensitivity of any one of the hydrophones can be determined from the purely electrical measurements described above. This method has now been established as the NPL primary

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standard in the frequency range 2 kHz to 500 kHz with typical overall uncertainties (95% confidence level) of ±0.5 dB. In both the techniques described here, measurements are made in a laboratory tank using discrete-frequency tone-burst signals, with gating and time-windowing techniques employed to isolate reflections from boundaries. For reciprocity, the measurements were made in a tank of dimension 2 x 1.5 x 1.5 m, and for the interferometer, a tank of only 1 x 0.4 x 0.4 m was used.

RESULTS AND DISCUSSION

Figure 1 gives the results of the calibration of a Brüel & Kjær 8103 hydrophone by the methods of interferometry and reciprocity, with the upper graph showing the absolute sensitivities and the lower showing the differences between the results. As can be seen, the differences are typically 0.4 dB or less which is considerably less than the combined uncertainties of the two methods. It is believed that the reciprocity values are the main source of the 0.9 dB discrepancy at 900 kHz since the hydrophones are becoming increasingly directional and much less sensitive at high frequencies, especially when used as projectors. Conversely, the interferometer results become less accurate at lower frequencies, mainly due to the restrictions on the echo-free time available for calibrations in the small interferometer tank, which increases the problems from acoustic reflections and transducer turn-on transients.

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REFERENCES


Figure 1 Above: results of calibration of a B&K8103 hydrophone by interferometry (+) and reciprocity (o) in units of dB re 1V/μPa. Below: the difference between the results of the two methods (interferometry-reciprocity).