Comparison of a Miniature, Ultrasonic, Optical Fibre Hydrophone with PVDF Hydrophone Technology

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Abstract - A miniature optical fibre hydrophone has been developed for the measurement of ultrasound in the range 1-30 MHz The acoustically sensitive element comprises a 23 μm thick polymer film mounted at the end of an optical fibre. When illuminated by laser light launched into the fibre, the polymer film acts as a Fabry Perot interferometer. An incident acoustic wave modulates the optical thickness of the interferometer thereby producing a corresponding intensity modulation in the light reflected from the film. The system was characterised in terms of sensitivity, frequency response and directivity using a broadband (1-30 MHz) ultrasonic field produced by nonlinear propagation obtained by driving a 1 MHz PZT source with a high amplitude 1 MHz toneburst. PVDF needle and membrane reference hydrophones were used as comparisons. The minimum detectable acoustic pressure of the optical fibre hydrophone was found to be 10 kPa in a 25 MHz measurement bandwidth with a wideband response to 30 MHz. The -3dB beamwidth at 10 MHz was 60°. Such performance is comparable to that achieved with PVDF hydrophone technology, with additional advantages of immunity to EMI, small physical size, a flexible probe-type configuration, robustness and potentially low cost. Among the applications that might benefit from these advantages are single-use applications such as the measurement of industrial CW fields in hostile environments and in vivo measurements of medical ultrasound exposure.

INTRODUCTION

Ultrasonic hydrophones such as those based upon piezoelectric PVDF sensing elements are widely used for characterising ultrasound fields [1]. There can, however, be problems associated with the electrical nature of piezoelectric devices including sensitivity to EMI and cable loading and resonance effects due to the connecting cable. Fragility, expense and the difficulties involved in fabricating small (< 100 μm) active element diameters for low directional sensitivity whilst retaining adequate acoustic sensitivity can also present limitations. We have recently developed a miniature optical fibre hydrophone [2], which, by virtue of its electrically passive nature, small active diameter and simplicity of construction, has the potential to overcome these disadvantages. The acoustically active element of this optical fibre hydrophone, shown schematically in Fig. 1, comprises a thin polymer film, a few tens of μm thick, acting as a low finesse Fabry Perot interferometer [3] mounted at the tip of an optical fibre.

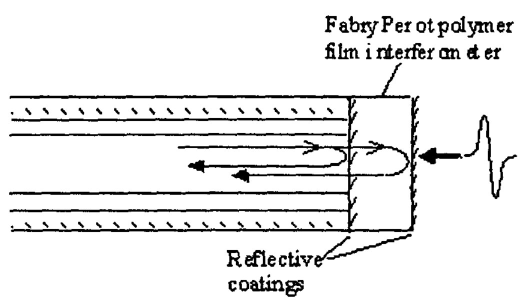

FIGURE 1 The acousically active tip of the optical fibre hydrophone.

An acoustic wave modulates the thickness of the film and hence the optical phase difference between laser light reflected from the two sides of the film. This produces a corresponding intensity modulation of the light reflected from the film. For optimum sensitivity and linearity, the interferometer is operated at a phase bias that corresponds to quadrature. An advantage of using a polymer film as an extrinsic interferometric acoustic sensing element, rather than the fibre itself [4,5], is that the low Young's modulus of polymers enables high acoustic sensitivity to be achieved, even when using a sensing film of only a few tens of μm thick, as is necessary to obtain a wideband acoustic response at MHz frequencies.

We report here a series of measurements to compare the sensitivity, frequency response and directionality of the new optical fibre hydrophone with those of a bilaminar membrane hydrophone and two types of needle hydrophone.

MATERIALS AND METHODS

Optical fibre hydrophone

The optical fibre hydrophone made use of a 50 µm core, all-silica fibre of numerical aperture 0.1 and outer diameter 0.25 mm. The Fabry Perot polymer sensing film, bonded to the cleaved end of the fibre, comprised a 0.25 mm diameter disk of 23 µm thick PET (polyethylene terephthalate) with a 40% optically reflective aluminium coating on one side and 100% reflective coating on the other, the two coatings forming the mirrors of the interferometer. The sensing film was interrogated using ~850 nm light from a wavelength-tuneable DBR (distributed Bragg reflector) laser diode, and the reflected intensity modulation transmitted back along the fibre for detection at a 25 MHz photodiode with integral transimpedance amplifier. Operation at quadrature was obtained by tuning the wavelength of the laser diode. The short path length of the polymer film interferometer (100 µm) meant that, once set at quadrature, the sensor was inherently insensitive to environmental thermal and pressure fluctuations, giving good stability.

Membrane and needle hydrophones

To compare with the optical fibre hydrophone and serve as a reference, measurements were made of the frequency response and directionality of a 50 µm bilaminar hydrophone manufactured by Marconi Ltd. It had a 0.5 mm diameter active area and was calibrated by the National Physical Laboratory (NPL), Teddington, UK. Comparative measurements were also made on two 9 µm needle hydrophones, one of diameter 75 µm, the other 200µm. These were manufactured by Precision Acoustics Ltd, Dorchester, UK.

Measurement method

Measurements of the frequency response and directional response of the optical fibre hydrophone and the hydrophones with which it was compared were made using the shocked wave calibration technique[6] as employed by NPL. The experimental set-up is shown in Figure 2 and comprises a 1.0 MHz, 1.52 inch diameter, non-focused PZT emitter, manufactured by Panametrics Inc, immersed in a 2 metre water tank together with the hydrophone under test.

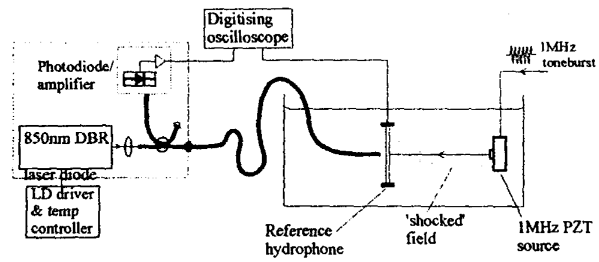

FIGURE 2 Experimental set-up.

The hydrophone under test was supported by a holder/manipulator featuring independent translations in the X, Y and Z directions, full 360° rotation of the hydrophone tip about the vertical axis and tilt adjustment about the horizontal axis. The emitter was driven by a 20 cycles sinewave toneburst amplified by a 52 dB rf-power amplifier. The output of each hydrophone was collected using a LeCroy 9310A 400 MHz digital storage oscilloscope.

RESULTS

Sensitivity:

	Sensitivity mV/MPa	Peak NEP kPa, 25MHz
Membrane $\phi = 0.5$ mm	60	5
Needle $\phi = 0.2$ mm	55	5
Needle $\phi = 0.075$ mm	10	30
Optical fibre	200	10

Table 1 Sensitivities and noise-equivalent pressures of the optical fibre, membrane and needle hydrophones.

Frequency response:

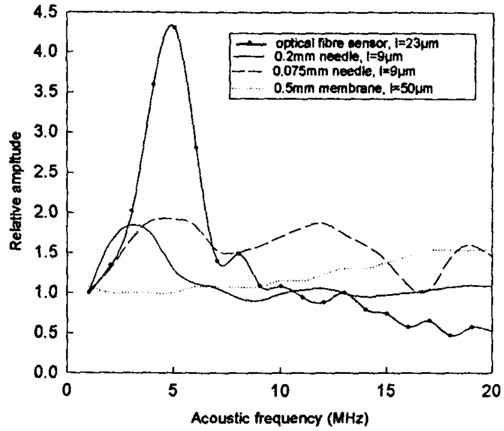

FIGURE 3 Frequency response of the optical fibre, membrane and needle hydrophones.

Directionality:

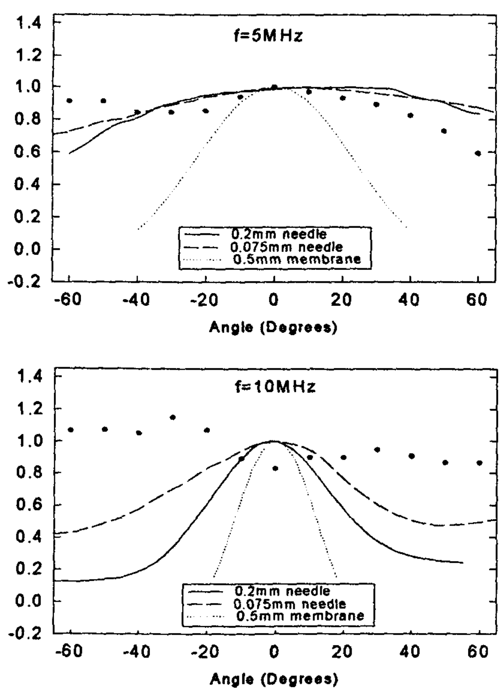

FIGURE 4 Directional response of the optical fibre, membrane and needle hydrophones.

All the measurements shown in the figures have been corrected for the frequency response of the photodiode.

DISCUSSION

The shocked wave technique was chosen because the sensitivities at acoustic frequencies between 1 MHz and 20 MHz could be determined from one measurement. The waves are relatively plain and wide, even for the high frequency components. This avoided the problems of extremely critical alignment for narrow, high frequency beams and spatial averaging errors when hydrophones of different size were compared.

CONCLUSIONS

The acoustic response of the optical fibre hydrophone extended to 30 MHz, with a minimum detectable acoustic pressure of 10 kPa measured with a 25 MHz bandwidth. The -3dB beamwidth at 10 MHz was 60°. These measurements show that the performance of the optical fibre hydrophone is comparable to that achieved with PVDF hydrophone technology, with additional advantages of immunity to EMI, small physical size, a flexible probe-type configuration, robustness and potentially low cost.

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