PRECISION ACOUSTICS

Fibre Optic Hydrophone System (FOHS)

The Fibre Optic Hydrophone System is a unique hydrophone type that was developed in collaboration with University College London and manufactured by Precision Acoustics Ltd. Whenever properties are reported in this data sheet they refer to those of a hydrophone system incorporating a Fibre Optic Hydrophone System and its interrogating optics unit.

The size of the active element of a hydrophone affects many properties including sensitivity, frequency response, directional response, dynamic range and noise equivalent pressure. This technical data sheet is prepared in compliance with IEC 62127 – part 3 [5]

The Fibre Optic Hydrophone System offers the smallest active element of any hydrophone in the Precision Acoustics Ltd product range. It is immune to Electro-Magnetic Interference and is thus ideal for a wide range of applications at frequencies from 1.0 MHz to 40 MHz, especially therapeutic ultrasound. It can also measure temperature change and thus enables users to simultaneously measure pressure waveforms and the ultrasonically induced heating arising from their absorption within the surrounding medium.

PRODUCT DESCRIPTION

The Fibre Optic Hydrophone System is based around a Fabry-Perot interferometer that is built onto the end of a specially prepared optical fibre. The transduction mechanism is entirely acousto-optic and there is no electrical signal travelling to/from the sensor tip and thus fibre-optic hydrophones have excellent immunity to Electro-Magnetic (EM) signals. As a result, the Fibre Optic Hydrophone System is ideally suited to the measurement of long duration (or continuous) signals that would otherwise be difficult with piezo-electric hydrophones. The fibre sensor and mounting chuck are also non-ferrous and therefore compatible for use with MRI equipment.

The Fibre Optic Hydrophone System sensors offer the smallest sensing element of any hydrophone in the Precision Acoustics Ltd product range. The active element is defined by the optically illuminated region at the tip of the fibre which is in turn defined by the fibre's core diameter (10 µm). A small active element also ensures that these hydrophones have a very broad directional response. However, the interferometric sensing technique yields an acoustic sensitivity that is much higher than comparable piezo-electric devices.

Another advantage of the Fibre Optic Hydrophone System is that it can measure temperature change. Therefore, by embedding the fibre sensors into tissue or tissue-mimicking material, it is possible to determine both the in-situ ultrasonic waveforms and the temperature rise that occurs when these signals are absorbed within the surrounding media.

Specification

Model Number	FOHS	
Sensor element dimensions	Fibre diameter:	125 µm
	Optically illuminated (element) diameter:	10 µm
Hydrophone dimensions	See Figure 1	
Weight of hydrophone	7 g (including connector)	
Transduction method	Fabry-Perot Interferometry	
Mean sensitivity in the range 2 MHz to 20 MHz	250 mV/MPa (additional data below)	
Device-to-device variation	± 3 dB	
Hydrophone frequency band	0.25 MHz to 50 MHz	
Measurement uncertainty	0.1 MHz to 1 MHz:	8 %
	1 MHz to 8 MHz:	9 %
	9 MHz to 20 MHz:	11 %
	21 MHz to 30 MHz:	12 %
	31 MHz to 40 MHz:	15 %
Output impedance of hydrophone system	50 Ω	
Orientation during use	Sensor tip pointing directly towards the acoustic source (see Figure 4)	

Dimensions

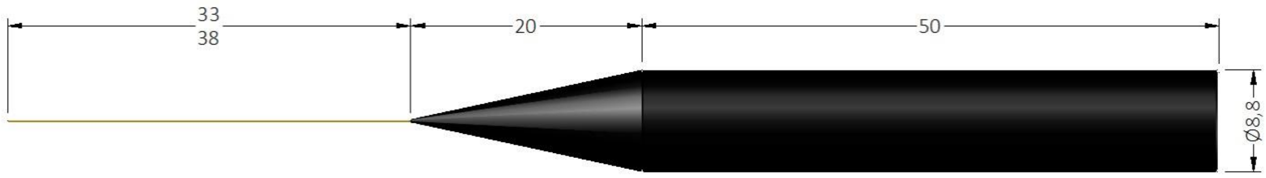

Figure 1 - Dimensioned drawing of Fibre Optic Hydrophone System within a fibre holder

SENSITIVITY AND FREQUENCY RESPONSE

All hydrophones have a frequency response that varies as a function of frequency. The theoretical basis of this response is well understood and described elsewhere. Figure 2 and Figure 3 show the typical end-of-cable loaded sensitivity for the membrane hydrophone when loaded by 50 Ω over the frequency range 0.1 MHz to 1 MHz and 1 MHz to 40 MHz respectively. The data displayed in Figure 2 was acquired by the National Physical Laboratory, London (NPL) whereas the data in Figure 3 was acquired by Precision Acoustics Ltd.

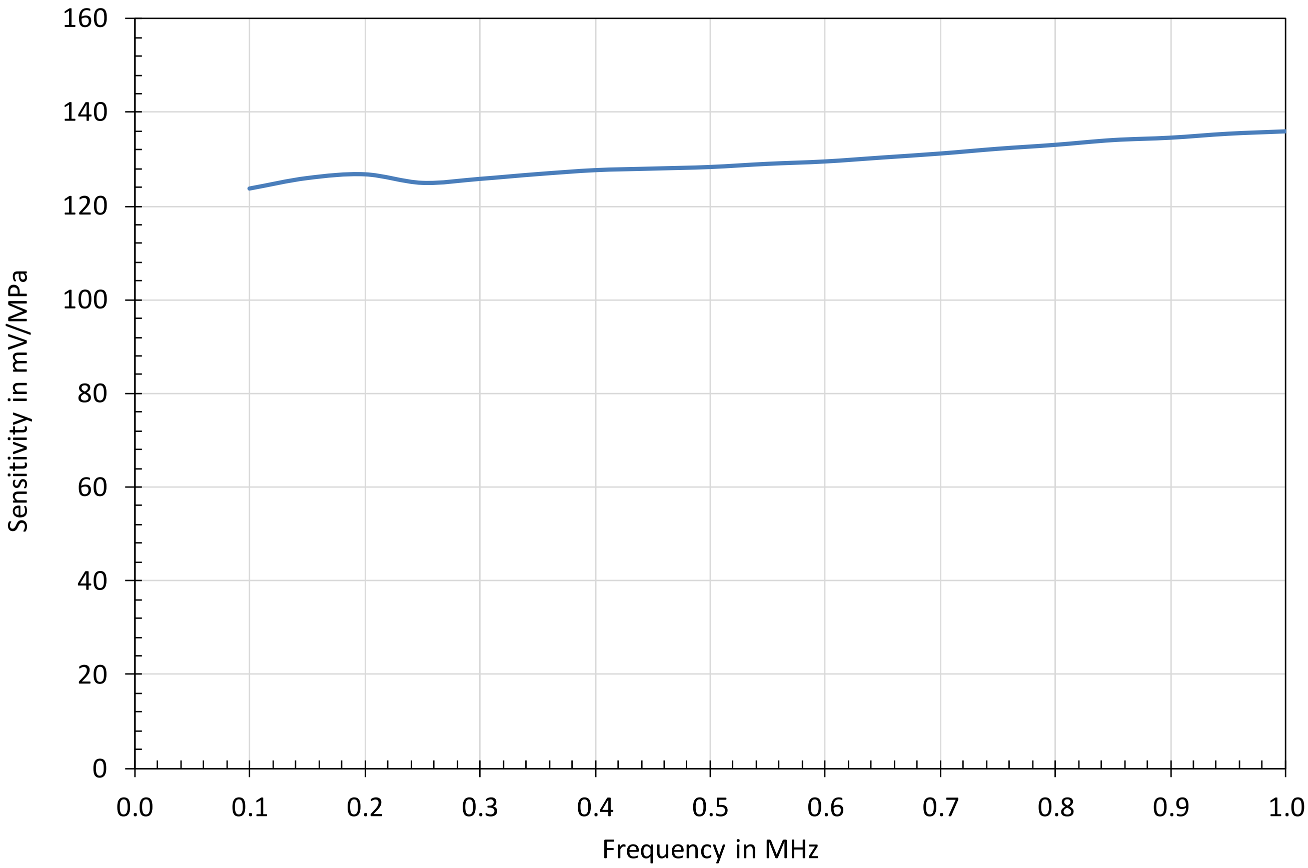

Figure 2 - Typical frequency response of a Fibre Optic Hydrophone System in the range 100 kHz to 1.0 MHz

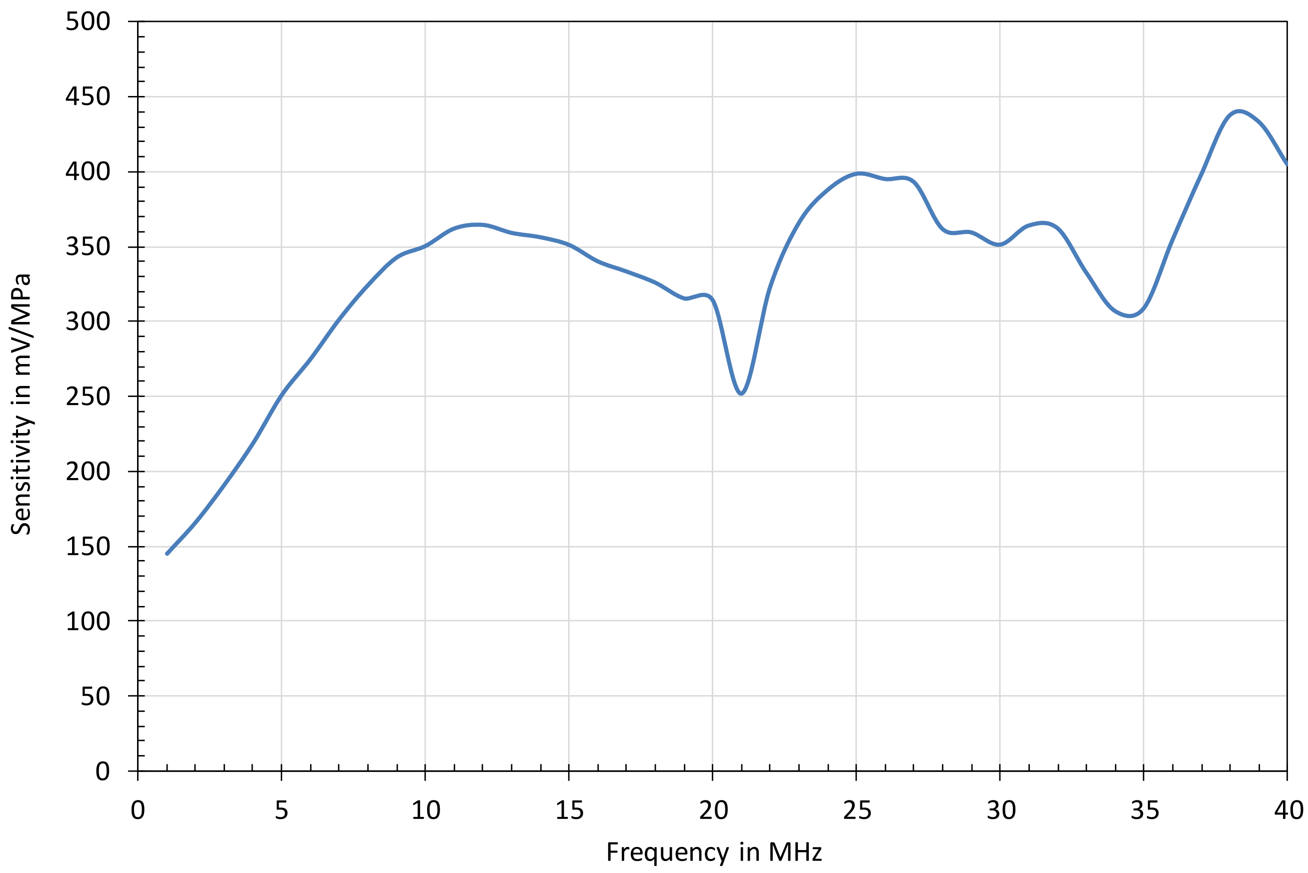

Figure 3 - Typical frequency response of a Fibre Optic Hydrophone System in the range 1.0 MHz to 40 MHz

Hydrophones used to make absolute measures of acoustic pressure should be calibrated at least once every 12 months. The hydrophone should be checked against a reference source on a monthly basis so that variations in sensitivity are identified sooner than the annual calibration interval.

The measurement uncertainty for the frequency response measurement was determined in accordance with the methods established in [1]. One of the main uncertainty contributions is that due to the calibration of the reference hydrophone used in the calibration, which itself is traceable to national primary standards.

DIRECTIONAL RESPONSE

Fibre-optic hydrophones have been previously shown [2] [3] to have a directional response that deviates from that predicted by the circular plane piston in a rigid baffle model. It has also been shown [4] that there are multiple wave modes propagating around the tip of these hydrophones and these are likely to have an impact on the directivity of fibre-sensors

The directional response of the hydrophone was established using the same nonlinear field as that used in the determination of the frequency response. The hydrophone was placed in a mounting fixture that permitted the precise position of the active element to be adjusted. The hydrophone was then adjusted so that there was less than 100 ns temporal shift of the recorded waveform when it was rotated in the field. This alignment ensured that the hydrophone was not displaced during rotation and therefore that any variations in received signal were due only to the directional response of the hydrophone. By recording the waveform generated by the hydrophone as a function of angle, the directional response at a range of frequencies could be established. The directional response of the Fibre Optic Hydrophone System at 1 MHz, 5 MHz, 10 MHz, 15 MHz, 20 MHz, 25 MHz, 30 MHz and 40 MHz has been plotted in Figure 5.

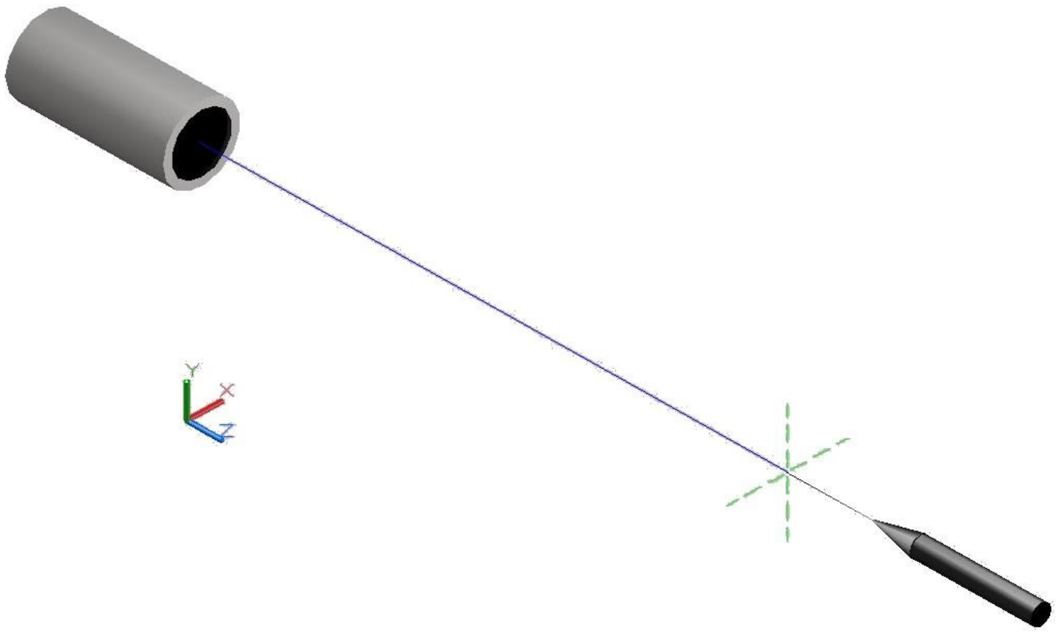

Figure 4 - Orientation of fibre-optic hydrophone during use

Figure currently unavailable

Figure 5 - Directional response of Fibre Optic Hydrophone System

Effective radius

The effective radius of the hydrophone was calculated from the angles at which the –3 dB and –6 dB points of a directional response curve occur in accordance with the methods described in [5] and the mean effective radius is shown in Figure 6. However, the IEC method fails at lower frequencies for this hydrophone.

Figure currently unavailable

Figure 6 - Effective radius of Fibre Optic Hydrophone System

DYNAMIC RANGE, LINEARITY AND ELECTROMAGNETIC INTERFERENCE

Lower dynamic limit

The noise equivalent pressure of the Fibre Optic Hydrophone System is ≈ 16 kPa with optical and acousto-optic effect accounting for the majority of this value.

Upper dynamic limit

Concerning the pressure threshold above which mechanical damage occurs to the hydrophone: this hydrophone has been designed to withstand ultrasonic pressures up to 10 MPa. Although hydrophones of this type have been used for ultrasonic fields that exceed 20 MPa, there is an elevated risk of damage. The supplier's advice should be sought if the hydrophone is to be used in fields containing acoustic pressure levels beyond 10 MPa. Furthermore, the hydrophone has been tested in a focussed field with focal intensity in excess of $700 W/cm^3$ and no damage was observed.

Concerning the pressure beyond which system nonlinearity exists: the sensitivity of the Fibre Optic Hydrophone System depends upon many factors including the interferometer transfer function (ITF) [6]. It has been shown [2] that as pressure amplitude increases, the operating point of the interferometer may move beyond the quasi-linear portion of the ITF. Consequently, there may be some output compression at higher pressures with reported hydrophone signals being as much as 10% lower than the true acoustic pressure once pressure exceeds 8 MPa

Susceptibility to electromagnetic interference

The sensor is intrinsically immune to EMI.

ELECTRIC OUTPUT CHARACTERISTICS

The output impedance of the FOHS control system is 50 Ω.

ENVIRONMENTAL ASPECTS

Temperature variation

This hydrophone can be used for measurement over an operating temperature range of 5 °C to 50 °C and can be stored over the range 5 °C to 50 °C. Exposure to temperatures above 60 °C has the potential to cause irreversible damage to the hydrophone.

This hydrophone assembly has been calibrated at a temperature between 19 °C and 25 °C. The sensitivity of the hydrophone will be a function of temperature and an increase in the sensitivity of 0.4 % per degree temperature rise should be expected.

Water quality

The hydrophone assembly has been designed for complete immersion in water and can easily withstand the hydrostatic pressure caused by 2 m of water. Although the hydrophone assembly can be used for prolonged periods (>48 h) of immersion, the hydrophone should be withdrawn from water and allowed to dry whenever it is not in use.

There are no specific operating requirements in terms of water quality for use of this hydrophone. However, hydrophone measurements standards such as the [7] [8] may have specific requirements for water quality.

Prolonged immersion in water that has not been deionized (e.g. tap water) can lead to a build-up of deposits on the hydrophone. Calcium carbonate deposits can be a particular problem in "hard" water areas and will lead to a loss of sensitivity of the hydrophone.

Other liquid media

Although designed for operation in water, the hydrophone assembly can be used in many other liquid media. It should be noted, however, that the calibration of this hydrophone was undertaken in water. Other materials present different acoustic impedance loads on the hydrophone active element and this is likely to affect the sensitivity of the hydrophone. Certain liquids should be avoided due to their chemically aggressive nature. Examples of materials that should be avoided are:

- concentrated acids (e.g. nitric acid, sulphuric acid);
- concentrated alkalis (e.g. sodium hydroxide);
- strong organic solvents [e.g. many aldehydes, many ketones, Dimethyl Chloride (DMC), dimethylformamide (DMF)].

As supplied, the only materials of the hydrophone assembly that are exposed to the surrounding liquid are Parylene and the polyvinyl chloride (PVC) cladding of the fibre jacket.

REFERENCES

[1] BIPM, *JCGM100: 2008 Evaluation of measurement data — Guide to the expression of uncertainty in measurement,* 2008.

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[7] IEC, *62127 Ultrasonics - Hydrophones - Part 1: Measurement and characterisation of medical ultrasonic fields up to 40 MHz,* 2013.

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