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Acoustics - Measurement of phase-shifted sensitivity of interferometric fiber-optic hydrophones

声学 干涉型光纤水听器相移灵敏度测量

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1 Scope

The document describes the measurement principle, the measuring set-up, the measurement conditions, the measurement procedure and the measurement uncertainty for measuring the sound pressure phase-shifted sensitivity of interferometric fiber-optic hydrophones by the interferometric fringe counting method, the Bessel function ratio method, the phase generated carrier demodulation method, the differential delay heterodyne demodulation method and the phase demodulation method using a 3 x 3 coupler.

The document applies to the measurement of the phase-shifted sensitivity of interferometric fiber-optic hydrophones in the frequency range 10 Hz to 20 kHz.

Note: where the phase-shifted sensitivity levels given by the above methods differ by more than 3 dB, the result obtained by the interferometric fringe counting method is taken as correct.

2 Normative references

The content of the documents listed forms indispensable provisions of this document through normative reference in the text. For dated references only the edition corresponding to that date applies; for undated references the latest edition, including all amendments, applies.

GB/T 3947-1996 Acoustical terminology; GB/T 4130-2017 Acoustics - Low frequency calibration methods for hydrophones; GB/T 7965-2002 Acoustics - Measurement of underwater acoustic transducers; GB/T 14733.12-2008 Terminology for telecommunications - Optical fibre communication; JJG 449-2014 Octave and fractional octave filters.

3 Terms and definitions

The terms and definitions given in GB/T 3947-1996, GB/T 4130-2017, GB/T 7965-2002 and GB/T 14733.12-2008 apply, together with those below.

3.1 interferometric fiber-optic hydrophone: hydrophone made with optical fibre as the sensing element and working on the principle of optical interference. Note: its characteristic is that the phase shift of the interfering light bears a fixed proportional relation to the change of sound pressure in the sound field.

3.2 phase-shifted value of optical interference: phase difference between the interfering light signals of the sensing arm and the reference arm of the interferometric fiber-optic hydrophone caused by the action of an external signal.

3.3 interferometric fringe counting method: method of obtaining the phase-shifted value of optical interference of an interferometric fiber-optic hydrophone caused by the action of an external signal by acquiring the number of interference fringes output by the hydrophone.

3.4 Bessel function ratio method: method in which the interference signal output by the interferometric fiber-optic hydrophone is expanded in a Bessel series and the ratio of the third harmonic to the fundamental of the signal, or of the fourth harmonic to the second harmonic, is used. Note: the phase-shifted value of optical interference measured by the Bessel function ratio method is also called the Bessel function argument.

3.5 phase generated carrier demodulation method: method of obtaining the phase-shifted value of optical interference of an interferometric fiber-optic hydrophone by demodulating the interference light signal output by the hydrophone after phase carrier modulation.

3.6 differential delay heterodyne demodulation method: method of obtaining the phase-shifted value of optical interference of an interferometric fiber-optic hydrophone by generating a differential delay heterodyne optical pulse pair which, after passing through the hydrophone, forms a heterodyne interference light signal that is then demodulated.

3.7 phase demodulation method using 3 x 3 coupler: method of obtaining the phase-shifted value of optical interference of an interferometric fiber-optic hydrophone by using the property that the interference light signals output at the three ends of a 3 x 3 coupler differ in phase by 2 pi/3, and demodulating the phase of the light signal output by the hydrophone.

3.8 standard hydrophone: transducer used for underwater acoustic measurement, stable in performance and absolutely calibrated; commonly used as the standard for establishing the underwater sound pressure reference and for transferring the sound pressure value. The definition is taken from GB/T 3947-1996, 7.82.

3.9 sound pressure phase-shifted sensitivity: ratio of the phase-shifted value of optical interference of the interferometric fiber-optic hydrophone caused by the action of a sound pressure signal to the free field sound pressure that existed, before the hydrophone was introduced into the sound field, at the position of the reference centre of the hydrophone. Note: the unit of the sound pressure phase-shifted sensitivity is the radian per pascal.

3.10 sound pressure phase-shifted sensitivity level: twenty times the logarithm to base ten of the ratio of the phase-shifted sensitivity to the reference phase-shifted sensitivity, the reference phase-shifted sensitivity being 1 rad/µPa. Note: the unit of the sound pressure phase-shifted sensitivity level is the decibel.

4.1 Interferometric fringe counting method - measurement principle

The intensity of the interference light signal output by an interferometric fiber-optic hydrophone under the action of an underwater sound wave is expressed by formula (3), whose symbols are: the interference light intensity voltage signal output by the hydrophone, in volts; the direct current component of the interference light signal, in volts; the alternating current component of the interference light signal, in volts; the phase-shifted value of optical interference output by the hydrophone, in radians; the angular frequency of the sound signal, equal to two pi times the frequency of the sound signal, that frequency being in hertz; the phase difference produced by external environmental factors, in radians; and time, in seconds. The equation itself is not reproduced here.

Figure 1 gives the time domain waveform of a typical interference signal of an interferometric fiber-optic hydrophone; the signal is clearly periodic.

Whenever the phase-shifted value of optical interference is a whole number n of pi radians, a crossing straight line exists along the time axis between the crests and the troughs of the interference signal fringes, as the broken line in Figure 1 shows; the number of fringes within half a period of the interference signal then corresponds to the whole number n. Formula (4) gives the phase-shifted value of optical interference output by the hydrophone under the action of the sound field as n times pi, with n not less than 1 and n a whole number.

In the frequency range 10 Hz to 1 kHz the measurement is made by the method recommended in GB/T 4130-2017. As Figure 2 a) shows, the interferometric fiber-optic hydrophone and the standard hydrophone are placed at the same depth in a standing wave tube, the output voltage of the standard hydrophone and the interference phase shift of the fiber-optic hydrophone are measured, and the phase-shifted sensitivity level of the fiber-optic hydrophone is obtained from formula (5), in which the amplitude of the output voltage of the standard hydrophone is in volts and the sound pressure sensitivity level of the standard hydrophone is in decibels with a reference value of 1 V/µPa.

In the frequency range 1 kHz to 20 kHz the measurement is made by the method recommended in GB/T 7965-2002. As Figure 2 b) shows, the interferometric fiber-optic hydrophone and the standard hydrophone are placed at the same depth under water, the distance between the standard hydrophone and the transmitting transducer and the distance between the fiber-optic hydrophone and the transmitting transducer being noted; the output voltage of the standard hydrophone and the interference phase shift of the fiber-optic hydrophone are measured, and the phase-shifted sensitivity level is obtained from formula (6), in which the two distances, from the reference centre of the transmitting transducer to the reference centre of the fiber-optic hydrophone and to the reference centre