Investigation on fiber laser vector hydrophone: theory and experiment
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ABSTRACT

A novel underwater fiber laser vector hydrophone is presented. Theoretical and experimental analyses are carried out to
test the performance of the hydrophone, which shows a sensitivity of 25 pm/g and a flat frequency response in the range
of 5 Hz–200 Hz are achieved. Field demonstration shows that the vector hydrophone has good directivity.

Keywords: fiber laser, vector hydrophone, accelerometer, directivity

1. INTRODUCTION

Fiber optic hydrophones have become one of the most promising acoustic detection devices for future operational sonar
systems due to their high sensitivity, wide dynamic range, immunity to EMI, and feasibility in multiplexing[1]. Over the
past thirty years, a great deal of research has been reported concerning the design, fabrication, interrogation, multiplexing
and application of the fiber optic hydrophones. Fiber laser sensors was proposed in the 1990’s, which offers an
alternative approach to fiber optic hydrophones. These fiber laser hydrophones (FLHs) make it possible to build a ultra
thin array with diameters of only several millimeters. In the past several years, there have been a number of reports about
DFB fiber laser hydrophones[2-6], which shows that DFB FLH can perform high sensitivity and small size for
underwater acoustic measurement.

Fiber laser hydrophone array was also reported in recent years. A 16 channel fiber laser hydrophone array was
demonstrated in the laboratory in 2006[7]. And in 2009, Goodman[8] reported the field test of a seabed four-element
fiber laser hydrophone array in Australia.

Vector hydrophone can not only detect the pressure of the acoustic wave, but also can measure the particle velocity or
the acceleration in the water[9]. So the target can be located by a single vector hydrophone array, which means the gain
of the vector hydrophone array is large than the conventional hydrophone array when the number of the array elements is
the same. In this paper we report a novel fiber laser vector hydrophone (FLVH). The sensitivity of the accelerometer is
analyzed and the vector hydrophone is tested in Qiandao Lake.

2. PRINCIPLE OF THE FIBER LASER HYDROPHONE

The key element of the FLVH is the fiber laser accelerometer (FLA). The proposed FLA is shown in Fig.1 and Fig.2.
Two brass diaphragms, as the sensing element, are installed in the sensor shell which is made of a thin-wall metal
cylinder. A mass is installed between the two diaphragms to induce larger deformation of the diaphragms due to the
acceleration. A DFB fiber laser, which is anchored at the sensor shell and the mass, will be elongated or shortened due to
the seismic wave. There are two holes at the side of the sensor shell. The water can fill the hydrophone from the two
holes, which can compensate the static pressure in the water.
Based on the theory of elasticity, the sensitivity of the sensor is analyzed to be

$$M_s = \frac{\Delta \lambda_B}{\alpha} = \frac{0.78 \lambda_B m}{\pi \left( \frac{r}{R} \right)^2 \left( 1 - \left( \frac{r}{R} \right)^2 \right)} \left[ \frac{1}{1 - \left( \frac{r}{R} \right)^2} \right] + E_f A \left[ \frac{1}{1 - \left( \frac{r}{R} \right)^2} \right]$$

where

$$D = \frac{E_m t^3}{12 (1 - \nu^2)}$$

in which $m$ is the mass, $r$ is the inner radius of the diaphragm, $R$ is the outer radius of the diaphragm, $E_m$ is the Young’s modulus of the diaphragm, $\nu$ is the Poisson’s ratio of the diaphragm, $t$ is the thickness of the diaphragm, $E_f$ is the Young’s modulus of the fiber, $L$ is the anchored length of the fiber laser.
Then three FLAs are assembled together to form a FLVH, which is shown in Fig. 3. The three FLA are mounted on a base which is installed on the shell of the FLVH. The FLVH is hung on a frame.

Fig. 3. The schematic of the FLVH

3. EXPERIMENT AND RESULTS

The FLA and a standard PZT accelerometer are both installed on a shaker to measure the sensitivity of the FLA. The interrogation of a fiber laser hydrophone can be achieved by using phase generated carrier (PGC) demodulation system [10], which is shown in Fig. 4. The test result is shown in Fig. 5. The sensitivity of the FLA is about 25 pm/g. The noise floor of the FLA is about $10^{-6}$ pm/√Hz at 100 Hz. So the minimum detectable signal of 40 μg can be achieved.

Fig. 4. The schematic of the interrogation system
In order to test the performance of the FLVHs, a field test is carried out. A FLVH, which is shown in Fig. 6, is installed 5 m depth under water. A sound source is put about 1 km away. The normalized responsivity of one direction of the FLVH is shown in Fig. 7.
From Fig. 7 it can be found that the FLVH has good directivity, which is nearly 20 dB. The other two directions has almost the same directivity, which shows the FLVH has good performance.

CONCLUSION

A novel fiber laser vector hydrophone is presented. The sensitivity of the FLA used in the FLVH is tested to be 25 pm/g. Due to its low noise floor of $10^{-9}$ pm/√Hz at 100 Hz, a minimum detectable signal of 40 μg is achieved. Field test shows that the FLVH has good performance, which implies the proposed FLVH is promising in the application of target location.

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REFERENCES


