Research on packaging technology for fiber optical acoustic sensor

Rui Li*[a], Wen Xiao[a], Dong Yao[a], Bingshi Xu[a], Lin Cong[a]
[a]School of Instrumentation Science and Opto-electronics Engineering, Beihang University, Xueyuan Road, Beijing, P. R. China +86-10-82339736

ABSTRACT

A micro acoustic sensor with inclined fibers was proposed to improve its sensitivity. In order to get the highest sensitivity within the micro structure, the relative positions of elements in sensor should be exactly located; especially the distance between fibers and membrane should be optimum. A packaging technology for this micro sensor assemblage and test is introduced. It is based on a packaging system composed of three parts: distance adjusting, intensity collection and data analysis. The distance adjusting part increases the operating distance with a step of 2μm. Meanwhile the received power is recorded by intensity collection part on line to get the intensity characteristic curve. Through the data analysis part, sensitivity curve, optimum operating distance, the highest sensitivity and optimum received power of the proposed acoustic sensor are got. An experiment was implemented to assemble and test a sensor whose angle between two fibers was 60° by the proposed packaging system. Its optimum operating distance and highest sensitivity were analyzed to be 30μm and 2.49μW/μm. The sensitivity of packaged sensor to standard acoustic signal is 16mV/Pa and SNR is tested to be 54dB.

Keywords: fiber acoustic sensor, sensitivity, optimum operating distance, packaging setup

1. INTRODUCTION

Fiber optic sensors offer many advantages over conventional sensors such as immunity to electromagnetic interference, small size, low weight, and safety even in an explosive environment. Besides that, with the characters of ultrahigh precision pointing and tracking as well as general platform stability, fiber optic vibration sensors are ideal for sensing the vibrations of components, sections of large space structures, airframes, turbines, helicopter gearboxes, civil structures, and so on.[1,2] For vibration sensing, the intensity modulation by phase or polarization is usually implemented for high precision. However either of them is easily affected by the environment, such as temperature, pressure, and corrosion.

In this article, a reflected intensity modulated micro acoustic sensor with inclined fibers was proposed with improved sensitivity. Because of the inclined fibers, the relative position between elements in sensor is strictly required. Especially the relative position between two inclined fibers and membrane determines the coupling ratio of the light from transmitting fiber reflecting into receiving fiber. However, the elements in sensor are so small that their relative positions are too hard to be ensured. On the other hand, theoretical research indicates that the operating distance is another important factor which affects sensor's sensitivity [3]. There is an existed optimum operating distance where the

*alex@asee.buaa.edu.cn; phone +86 010-82339736; fax +86 010-82339736

International Symposium on Photoelectronic Detection and Imaging 2009: Material and Device Technology for Sensors, edited by Xu-yuan Chen, Yue-lin Wang, Zhi-ping Zhou, Qing-kang Wang, Proc. of SPIE Vol. 7381, 73810U · © 2009 SPIE
CCC code: 0277-786X/09/$18 · doi: 10.1117/12.835680

sensor has the highest sensitivity. The confirmation of optimum operating distance and precise adjusting for micro sensor are also difficult problems.

A packaging technology for this micro acoustic sensor assemblage and its test is introduced. It is based on the precision adjusting system, data record and analysis system. The strict relative position of elements is implemented and the optimum operating distance is confirmed and adjusted.

2. METHODS AND CONFIGURATION

2.1 Principles of sensor

Reflective intensity modulated fiber acoustic sensor with inclined fibers is composed by membrane, transmitting and receiving fibers, as well as light source and photon detector. The membrane is used to sense the air vibration caused by acoustic signal and to modulate the reflected intensity. In the sensor head, transmitting fiber and receiving fiber are integrated within a glass block so that the two beams coming out of them make a certain tilt angle α. Figure 1 depicts the operation principle of the sensor [4]: the light from the light source is coupled into the transmitting fiber. Then the light is projected from the end of transmitting fiber onto the membrane. The reflected light is partly coupled into the receiving fiber and converted to an electric signal using a photodiode. When the membrane senses vibration, a variable intensity is detected by the photodiode.

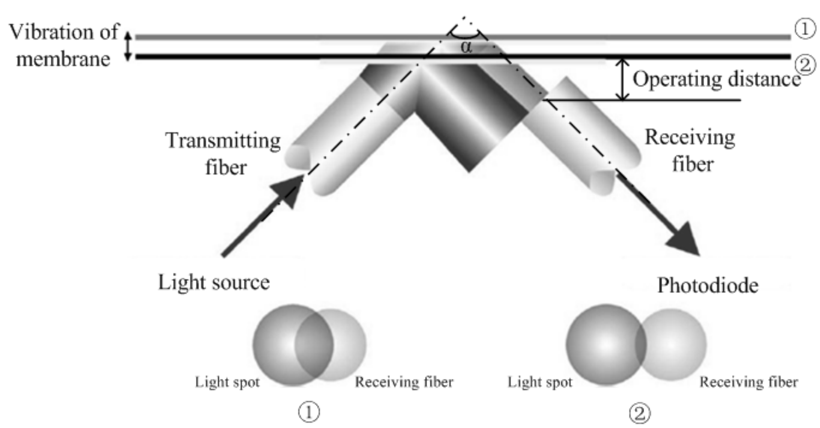

Fig.1 Principle of fiber acoustic sensor

In the reference [3], the influence of angle α to received power is introduced. It indicates the linear relationship between α and sensitivity of sensor. Figure 2 is the experimental result of our research on the influence of angle to the corresponding highest sensitivity of sensor when α is below 60°. We can get that the higher sensitivity is got with larger angle. In order to express the influence more exactly, a curve fitting is implemented and the fitting function is

$$y = 0.578e^{33.954/x} - 0.490 \tag{1}$$

Where y is the highest sensitivity of sensor and x is angle between two fibers. The fitting correlation coefficient is 0.9996 which means that the function fits the experimental result very well.

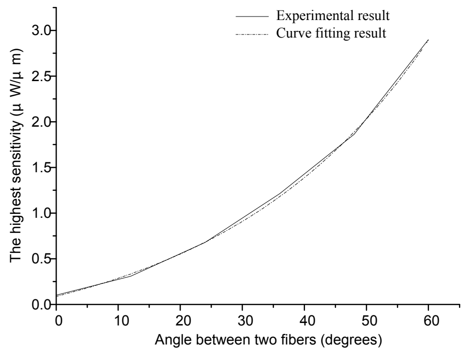

Fig.2 Influence of angle to the highest sensitivity

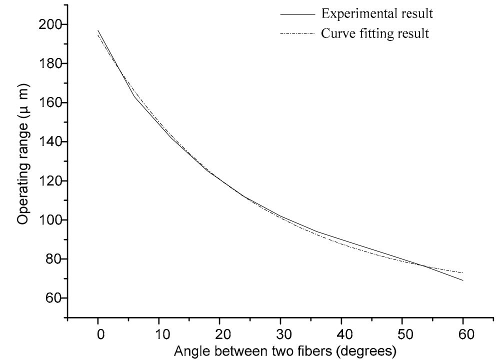

Fig.3 Influence of angle to operating range

For acoustic sensor, distortion degree is another important index. Reference [5] indicates that the distortion degree of micro acoustic sensor is related with its operating range. Operating range is the distance range where the sensor's highest sensitivity decreases to 3dB. Our experimental result shows the influence of angle α to operating range in figure 3. The fitting function is

$$y = 133.586e^{-\frac{x}{24.920}} + 60.898 \tag{2}$$

From figure 3, we can get that operating range decreases with the angle increase. But even the angle is 60°, the operating range is still about 70μm which is much more than the vibration amplitude of membrane. Hence, in order to get the sensitivity as high as possible, the angle of the packaged sensor in this paper is 60°.

2.2 Packaging technology and system

The proposed packaging system is shown in figure 4. It is composed by three parts: distance adjusting, intensity collection and data analysis.

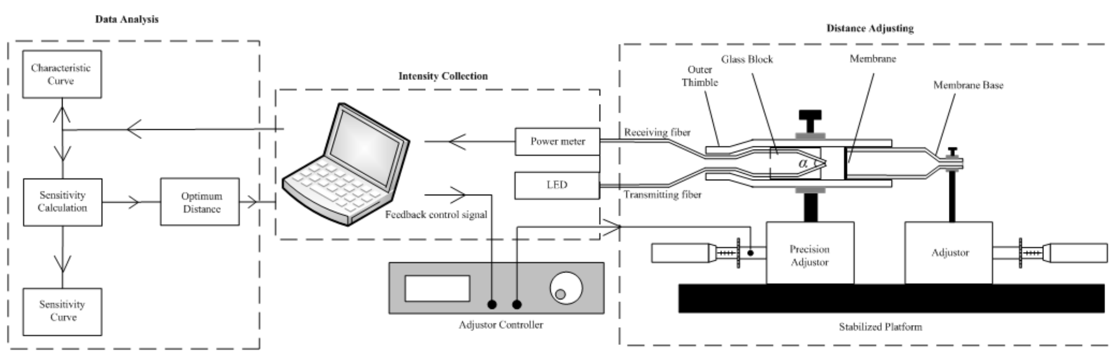

Fig.4 Illustration of packaging system

In the distance adjusting part, the elements in sensor head are located at the two adjustors. A glass block with two inclined grooves of angle of 60° was used to fix fibers. Core diameters of transmitting fiber were 62.5/125μm. And core diameters of receiving fiber were 100/125μm.Their numerical apertures were both 0.22. The end surfaces of two fibers were cut to plane. The glass block was fixed in the outer thimble through a base flat. The symmetry axis of two fibers should be superposition with central axis of outer thimble. The outer thimble was fixed with precision adjustor (Melles Griot-ANH001/MD). Membrane was attached to membrane base. And membrane base was fixed with adjustor. Considering of the requirement of no metal element, the base flat, outer thimble and membrane base were made of ceramic. Adjustor and precision adjustor were located at a stabilized platform. Membrane base was assembled into outer thimble and could glide smoothly. Cooperation between outer diameter of membrane base and inner diameter of outer thimble could ensure the perpendicularity relationship between the symmetry axis of fibers and the membrane.

When the sensor head was fixed well, transmitting and receiving fibers were connected with LED and power meter (JDSU- OPL55) to make the online adjusting system to measure and analyze the output power of LED P_0. Computer sent signal to adjustor controller to decrease the operating distance by precision adjustor with a step of 2μm. Meanwhile the received power P_r was read out by power meter and recorded by computer. Then the received intensity characteristic curve of sensor would be got. The curve showed the relationship between received power and operating distance. P_{max} is the largest received power. If $P_{max} \geq 70\% \times P_0$, it indicated that the perpendicularity relationship between the symmetry axis of fibers and the was correct. Otherwise, the outer thimble and membrane base should be adjusted over again. For acoustic sensor, the output signal was the variable quantity of received power caused by disturbance at the certain operating distance. Hence the sensitivities of sensor at different operating distance would be got through the derivative of received power with respect to operating distance. Then we would get sensor's sensitivity curve and its highest sensitivity S_{opt}, as well as the optimum operating distance L_{opt}. And the optimum received power P_{opt} would also be got trough L_{opt} and received intensity characteristic curve.

P_{opt} was sent back to computer for reference. Computer sent the feedback control signal to the adjustor controller to increase the operating distance of the sensor. Meanwhile the online intensity collection system was working. The received power P_n compared with P_{opt}. When P_n=P_{opt}, the corresponding operating distance was considered to be optimum. Then the sensor should be immediately assembled. During the period of assemblage, the received power P_n was watched all the while. And slight adjusting was implemented to make the P_n constant.

3. RESULTS AND DISCUSSIONS

According to the process introduced above, the received intensity characteristic curve of sensor was shown in figure 5. There were no discrete points or discontinuities which indicated that the glide of membrane base in outer thimble was smooth.

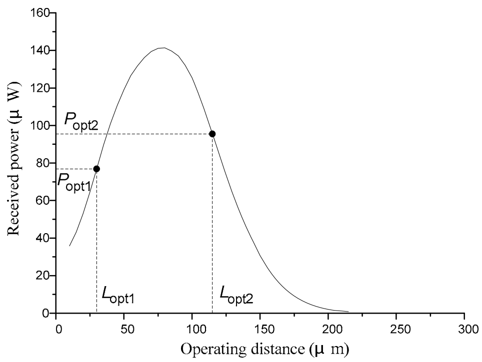

Fig.5 Received intensity characteristic curve

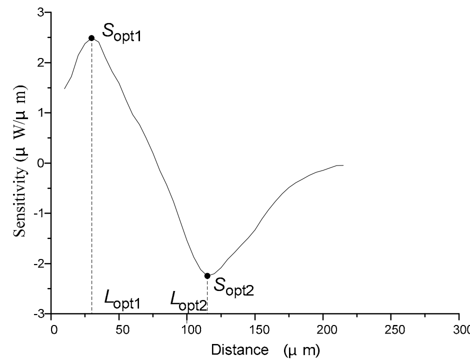

Fig.6 Sensitivity characteristic curve

The sensitivity curve of sensor would be got through the derivative of received power with respect to operating distance, as shown in figure 6. There were two extreme points which corresponded to the highest sensitivity on the front and back slope of intensity characteristic curve. We could get that the highest sensitivity on front slope was S_{opt1}=2.49μW/μm. Its corresponding operating distance was L_{opt1}=30μm, optimum received power was P_{opt1}=76.77μW, and operating range was [10μm, 55μm]; The highest sensitivity on back slope was S_{opt2}=-2.25μW/μm. Its corresponding operating distance was L_{opt2}=115μm, optimum received power was P_{opt2}=95.43μW, operating range was [95μm, 155μm]. Hence, the highest sensitivity on front slope was larger than the one on back slope. While operating ranges on two slopes were opposite. For acoustic sensor, the sensitivity was the key performance parameter. The vibration amplitude of membrane caused by acoustic signal was about several microns. We could get that the optimum operating distance L_{opt1} was more suitable for acoustic sensor.

The computer took P_{opt1} as reference and sent feedback signal to the adjustor controller. The operating distance was increased. It would be not optimum until matched the conditions of P_n-P_{n-1}>0 and $|P_n-P_{opt1}|$<1μW, where P_{n-1} was the last received power before P_n. Then the sensor was packaged. The packaging force could cause distance slight change. Hence, during the packaging period, the intensity collection system was still working and the received power should be watched all the while. A real-time adjusting was made. A photo of actual packaged sensor was shown in figure 7. A LED light source whose output power was about 200μW and a photodiode module (Agilent-HFBR2416) were used to test the performance of packaged sensor. Acoustical pressure of test signal was 1Pa and its frequency was 1kHz. Output signal was shown in figure 8. Its sensitivity was about 16mV/Pa and SNR was tested to be 54dB.

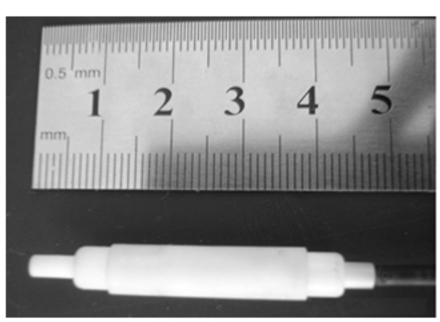

Fig.7 The photo of packaged fiber acoustic sensor

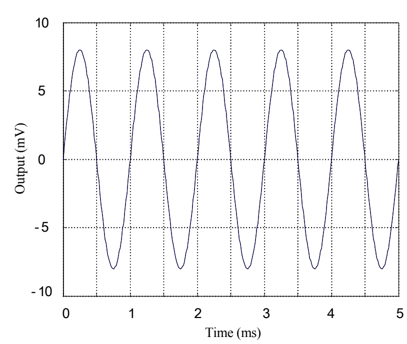

Fig.8 The response of sensor to sound pressure level

4. CONCLUTION

In this paper, a packaging technology and system for fiber acoustic sensor with inclined fibers has been presented. Transmitting and receiving fibers of sensor were fixed to angle of 60° by glass block with inclined grooves. Through precision adjusting part and online intensity collection part, the received intensity characteristic curve of sensor was got. Then the sensitivity curve optimum received power P_{opt1} of sensor was given by data analysis part and the optimum received power was confirmed. Computer took P_{opt1} as reference to adjust operating distance to be optimum. Then sensor was packaged and tested. Test result indicated that the sensor had the sensitivity of 16mV/Pa and SNR of 54dB. This packaging system would be a good experimental flat for the research on fiber acoustic sensor, and would also be a primary exploration for its manufacture.

REFERENCES

[1] Alexander Kots, Alexander Paritsky, "Fiber optic microphone for harsh environment," Proc.SPIE 3852, 106-112 (1999).

[2] S. Binua, V.P. Mahadevan Pillaia, N. Chandrasekaranb, "Fibre optic displacement sensor for the measurement of amplitude and frequency of vibration," Optics & Laser Technology 39 (8), 1537-1543 (2007).

[3] P.B. Buchade, A.D. Shaligram, "Influence of fiber geometry on the performance of two-fiber displacement sensor," Sensors and Actuators A 136, 199–204 (2007).

[4] Marco Feldmann, Stephanus Büttgenbach, "Microoptical Distance Sensor with Integrated Microoptics applied to an Optical Microphone," Proc. IEEE Sensors, 769-771 (2005).

[5] Jose Brandao Faria, "A Theoretical Analysis of the Bifurcated Fiber Bundle Displacement Sensor," IEEE Transactions on Instrumentation and Measurement 47, 742-747 (1998).