

Chapter 3

Research on OFDR Pressure Sensor Based on PDMS



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Abstract OFDR, as a new type of optical fiber sensor, can be sensitive to a variety of physical quantities, such as pressure and temperature. Physical parameters can be measured by using different materials to wrap the optical fiber. To improve the accuracy of OFDR sensing, researchers focus on processing the fiber structure, such as adding fiber gratings. These solutions increase sensor manufacturing cost and manufacturing complexity while improving accuracy. This paper proposes a low-cost OFDR sensor and pressure measurement method, using PDMS flexible material to wrap ordinary single-mode quartz fiber, and using a self-made pressure test platform for pressure measurement. Experimental measurement shows that this optical fiber pressure sensor has good linearity and repeatability. The results show that the linear fit of the sensor reaches 0.99, and the measured pressure can reach 20 N (24 kPa). At the same time, the sensor has good stability, so it has engineering application value.

3.1 Introduction

As a new type of sensing technology, optical fiber sensing technology has been greatly developed in recent decades [1]. Fiber optic sensors have many advantages over traditional sensors, including anti-electromagnetic interference, light weight, small size, high sensitivity, and easy implementation of multiplexing or distributed sensing [2]. The research on fiber optic sensors mainly focuses on strain, temperature, and vibration [3]. Among them, fiber grating sensors [4], fiber optic gyroscopes, and fiber current sensors have been widely used.

Optical Frequency Domain Reflectance (OFDR) is an optical fiber sensing technology based on the principle of Rayleigh backscattering [5]. It can measure temperature and strain in a distributed manner by using the inherent structural defects and

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weak backscattering caused by damage in the optical fiber. OFDR has the advantages of high spatial resolution and high accuracy. It only needs one scan to obtain all the data in the measurement fiber. The current research on OFDR focuses on improving the strength of back reflection by changing the internal structure of the fiber, such as fiber grating and fiber tapering, which increases the accuracy and greatly increase the cost.

This paper proposes a low-cost distributed flexible sensor structure, using PDMS material to wrap ordinary single-mode fiber to establish the relationship between pressure and fiber strain. PDMS is a flexible material with good stability, and is often used as a pressure material in the laboratory. By changing the ratio of PDMS stock solution and curing agent to obtain flexible substrates of different hardness, the relationship between fiber strain and pressure can be changed to obtain different pressure ranges, accuracy, and resolution.

3.2 OFDR Optical Fiber Sensing System

3.2.1 Measurement System Structure

The sensing system of the fiber sensor is composed of the optical fiber sensing unit, OFDR fiber demodulation equipment, a computer, and an optical fiber jumper. The sensing system with a double fiber junction is shown in Fig. 3.1, which is composed of two circular structures with a diameter of 2 mm. The test signal can directly escape from the circular junction that exceeds the maximum bending curvature of the optical

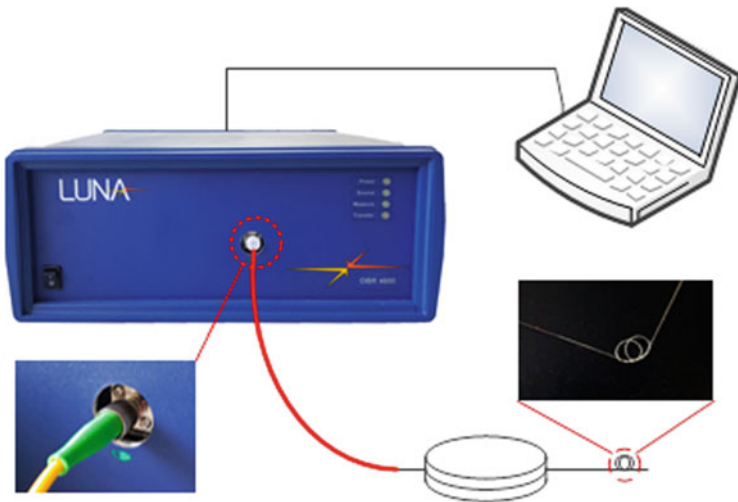


Fig. 3.1 The sensing system with a double fiber junction

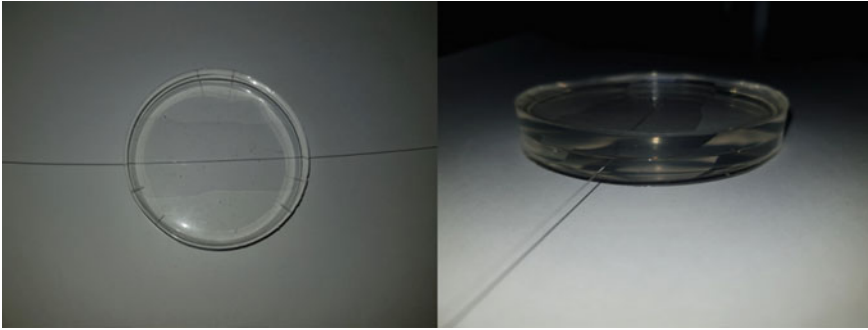


Fig. 3.2 Pressure sensor

fiber. This structure can prevent the end face reflected signal from covering the weak back Rayleigh scattered signal, which is generated at the end of the fiber, which is a low-cost solution.

The optical fiber demodulation equipment was LUNA's OBR4600, its spatial resolution can reach 0.01 cm, and strain measurement error is less than $1 \mu\epsilon$. This experiment uses 1 cm resolution, 1 m sensing distance, and 1 cm sensing interval. Use FC-APC fiber optic jumper to splice with the sensing unit.

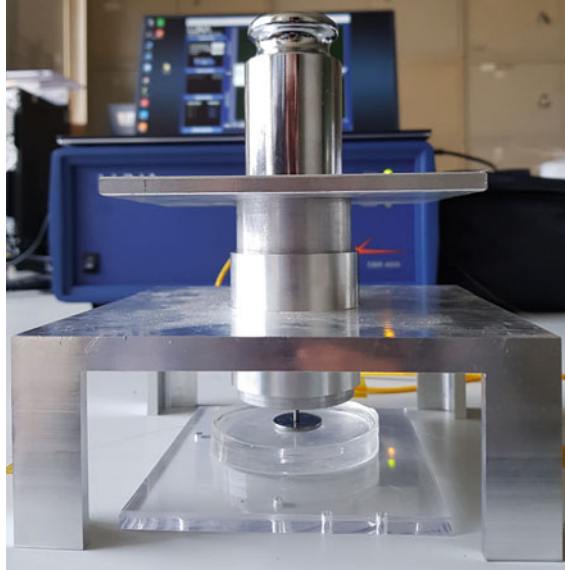
3.2.2 Pressure sensor

First, the mixture is uniformly stirred, wherein the mass ratio of the PDMS liquid to the curing agent in the mixture is 9:1. Slowly pour the liquid mixture into two containers and place it horizontally in a vacuum machine for 30 min. The vessel was then placed in an incubator, set at 60°C curing, the curing time 2 h. After curing, the PDMS is peeled and taken out of the container, one of which is the lower surface and the other is the upper surface. The single mode optical fiber having a diameter of $125 \mu\text{m}$ straightened passes between the upper and lower surfaces, fixed with glue to form a pressure sensor. The pressure sensor is shown in Fig. 3.2.

3.2.3 Pressure Test Bench

The test system uses a pressure test bench as shown in Fig. 3.3 to apply pressure.

When measuring, place the weight on the bearing platform, and insert the cylindrical structure under the bearing platform into the center of the bearing platform. There is a cylindrical structure with a smaller radius under the bearing platform, which forms a solid-shaped, fixed-size contact surface with the sensor placed under it. The pressure can be changed by changing the mass of the weight, and the pressure

Fig. 3.3 Pressure test bench

applied to the surface of the pressure sensor can be changed by changing the contact surface.

3.3 Experimental Results

The experiment uses linear pressurization. Select the step length of the weight to be 100 g for continuous pressure. The experimental results are shown in Table 3.1. When the mass of the weight is 1900 g, continue to increase the 100 g weight, the optical fiber strain value obtained by the demodulator does not change, and the strain value fluctuates after the mass of the weight continues to be increased. Therefore, set the end-point of pressure measurement to 2000 g for repeatability test. The first set of measurement results are linearly fitted, and the results obtained are shown in Fig. 3.4. The experimental results show that the sensor has good linearity, and the degree of fit reaches 0.99.

Because the experimental results show that when the pressure value of the sensor reaches 2000 g, there will be residual strain inside. As a result, the strain value measured by the interrogator will not return to zero. After all the weights are removed, the strain will continue for a while. So, after the last set of measurements, first remove all the weights, let the measurement system stand for 1 min, and then repeat the application of weights after resetting the interrogator to zero for repeatable measurement. Displayed equations are centered and set on a separate line. The repeatability measurement results are shown in Table 3.1. The repeatability measurement

Table 3.1 The repeatability measurement results

| Mass (g) | Group 1 | Group 2 | Group 3 | Group 4 | Pressure (MPa) |
|----------|---------|---------|---------|---------|----------------|
| 100 | 18 | 19 | 24 | 20 | 0.001209 |
| 200 | 40 | 48 | 50 | 50 | 0.002418 |
| 300 | 66 | 67 | 71 | 74 | 0.003627 |
| 400 | 91 | 92 | 100 | 100 | 0.004836 |
| 500 | 112 | 113 | 121 | 125 | 0.006045 |
| 600 | 135 | 138 | 130 | 145 | 0.007254 |
| 700 | 158 | 161 | 166 | 164 | 0.008463 |
| 800 | 174 | 184 | 178 | 186 | 0.009672 |
| 900 | 193 | 205 | 209 | 210 | 0.010881 |
| 1000 | 211 | 217 | 227 | 229 | 0.01209 |
| 1100 | 227 | 235 | 246 | 244 | 0.013299 |
| 1200 | 250 | 256 | 272 | 271 | 0.014508 |
| 1300 | 262 | 280 | 289 | 288 | 0.015717 |
| 1400 | 280 | 298 | 311 | 306 | 0.016926 |
| 1500 | 301 | 315 | 329 | 324 | 0.018135 |
| 1600 | 319 | 338 | 348 | 347 | 0.019344 |
| 1700 | 335 | 348 | 366 | 364 | 0.020553 |
| 1800 | 351 | 372 | 384 | 380 | 0.021762 |
| 1900 | 369 | 390 | 404 | 401 | 0.022971 |
| 2000 | 369 | 400 | 420 | 416 | 0.02418 |

Fig. 3.4 Single pressure measurement result and linear fitting curve graph

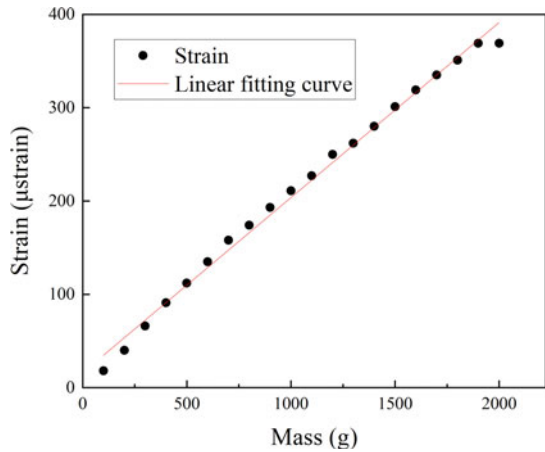
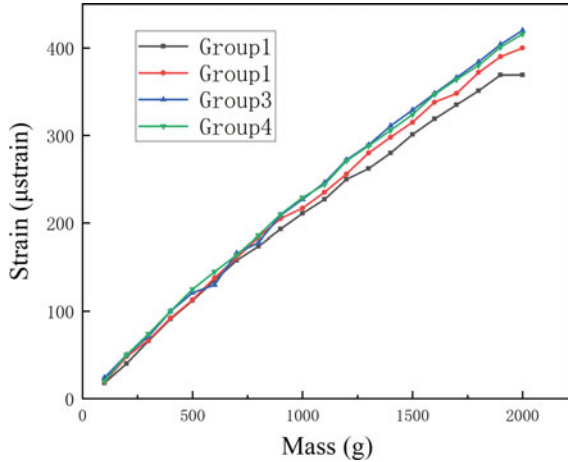


Fig. 3.5 Repeatability measurement result graph



results are shown in Fig. 3.5. The measurement results show that the sensor has good repeatability.

After the third measurement, the stability of the sensor gradually increased, and the repeatability was better. The reason for the analysis may be, after the manufacturing was completed, the inside of the sensor was not fully contacted, and the glue material was too hard. After the first two measurements, the internal structure of the sensor was stable, so the stability was slightly improved.

3.4 Conclusions

The optical fiber pressure sensor based on PDMS material drives the optical fiber to produce strain through the deformation produced by the PDMS material and establishes a stable connection between pressure and optical fiber deformation when pressure is applied. A stable pressure response characteristic can be achieved with ordinary single-mode fiber, and the linearity of measurement can be as high as 0.99 under the constant temperature and stable environment of the laboratory. The pressure measurement can be done at a lower cost.

References

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