Detection of Acoustic Emission Signals with the Fabry-Perot Interferometer Type Optical Fiber Sensor

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ABSTRACT: In order to improve the convenience in handling for measuring acoustic emission (AE) signals with optical fibers, an application of the Fabry-Perot interferometer to optical fiber AE sensor was investigated. The Fabry-Perot interferometer made of a pair of fiber Bragg gratings was adhered to the inside of a cylindrical sensing block for detecting the out-of-plane component of the displacement caused by AE waves. It was demonstrated that the proposed sensor could detect artificial AE signals due to steel ball dropping. Characteristics of the sensor were discussed by comparing with the result of the piezoelectric sensor.

1 INTRODUCTION

Various type of optical fiber acoustic emission (AE) sensors that are known to have advantages of robustness against electromagnetic noise, resistance to water, applicability in high temperature, etc. have been proposed in order to overcome difficulties in using conventional piezoelectric AE sensors [1-9]. AE measurement with interferometer type sensors is performed by paying attention to the change of the light intensity so that only the light source and the optical detector are required to construct the monitoring system, while the sensors based on other principles sometimes need equipment to examine wavelength shift, traveling time of the light, etc. One of the weak points of optical fiber sensors in comparison with the conventional piezoelectric sensors is the cost of the equipment for operation. Therefore, interferometer type sensors seem to be suitable from this point of view.

We have developed the Mach-Zehnder interferometer type optical fiber AE sensor with a cylindrical sensing block for the purpose of usability, such as detecting component and portability, same as conventional piezoelectric AE sensors [7]. However, handling of a reference fiber which composes the interferometer significantly affects the stability of sensing so that the ingenuity of fiber holding or the extra equipment avoiding the influence of disturbance are sometimes required. Since the Fabry-Perot interferometer is constructed without the reference fiber, the sensor based on the Fabry-Perot interferometer is preferable from the viewpoint of the sensing stability due to fiber handling. Although some Fabry-Perot interferometer type AE sensors have been already proposed [1,3], those sensors seem to be not always convenient because of requiring precise assembly to construct the interferometer. In this study, the Fabry-Perot interferometer made of fiber Bragg gratings (FBGs) was applied to the AE sensor in order to improve the convenience in handling, and the proposed sensor was used to detect artificial AE signals caused by dropping the steel ball.

2 PRINCIPLE AND STRUCTURE OF THE SENSOR

2.1 *Principle of the Fabry-Perot interferometer*

The schematic of the Fabry-Perot interferometer type optical fiber sensor is shown in Figure 1. Some power of light provided into the fiber is reflected at the point where made a half mirror, while the rest power of light is transmitted to the endpoint of the fiber and is reflected by a full mirror. Therefore, the interference is occurred caused by the phase difference in accordance with the change of the distance between the two mirrors. The intensity of the interference light is described in Equation 1.

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\left({}^{4\pi\Delta l}/_{\lambda}\right) \qquad (1)$$

where I: Intensity of the interference light [mW], I_1: Intensity of the reflected light at the half mirror [mW], I_2: Intensity of the reflected light at the full mirror [mW], Δl: Change of the distance between the half mirror and the full mirror [nm], λ: Wavelength of the light [nm]

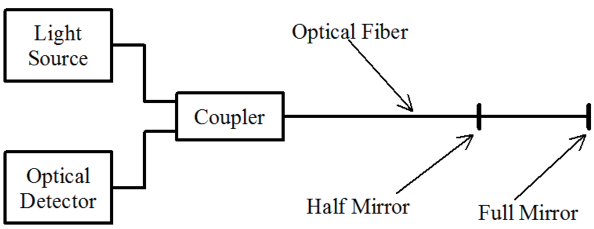


Figure 1: Schematic of the Fabry-Perot interferometer type optical fiber sensor

This means that the AE sensor can be made by preparing a structure that the distance between the half mirror and the full mirror is changed according to AE waves.

2.2 *Structure of the sensor*

In order to prepare the mirrors of the Fabry-Perot interferometer, it is known that FBGs, diffraction gratings that only reflect the light of the specific wavelength called Bragg wavelength, are applicable. In this study, the single mode UV coated silica fiber of 0.25 mm in diameter introducing FBGs at the position where keep a distance of 2 mm from the end of the fiber as shown in Figure 2 was used. Each length of the FBG is 1 mm and the distance between two FBGs is 1 mm. The reflectivity of the FBG located at the connector side was set to 50 %, therefore that acts as the half mirror. On the other hand, the other FBG located at the pigtail side acts as the full mirror because the reflectivity was set to 91 %. The Bragg wavelength and the bandwidth of the reflection represented by the parameter called the full width at half maximum (FWHM) of both FBGs were 1548.94 nm and approximately 0.35 nm, respectively.

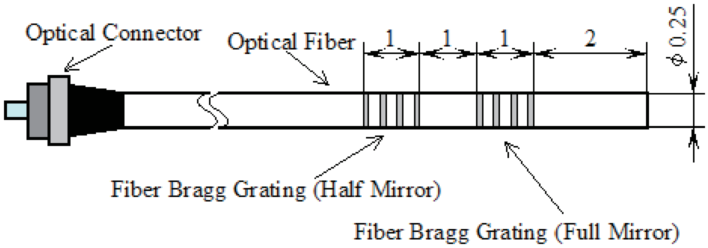
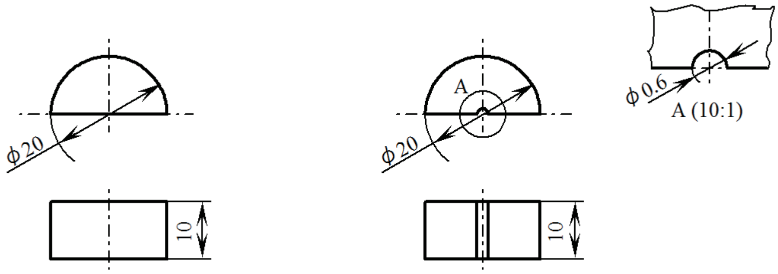


Figure 2: Fabry-Perot interferometer made of FBGs

A pair of polycarbonate blocks as shown in Figure 3 that were longitudinally halved the cylindrical geometry was used for making the sensing block. The interferometer part of the fiber mentioned above was adhered to the grooved block (Figure 3(a)) with cyanoacrylate adhesive by putting the fiber on a half-round groove. Then, this block and the non-grooved block (Figure 3(b)) were tightly bonded facing the flat surfaces with cyanoacrylate adhesive. By attaching the bonded block to the specimen, AE waves are propagated to the block in the longitudinal direction by way of the bottom of the block so that the out-of-plane component of the displacement caused by AE waves can be detected. Since the fiber related sensing was settled on the central axis of the cylindrical geometry, the sensor is expected to have no directivity. It is also notable that the sensor is convenient for handling since the whole interferometer part is embedded in the block. Figure 4 shows the appearance of the proposed sensor.



(a) Grooved block (b) Non-grooved block

Figure 3: Components of the sensing block

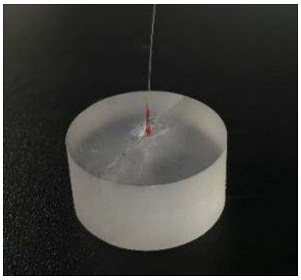


Figure 4: Appearance of the proposed optical fiber AE sensor

3 DETECTION OF ARTIFICIAL AE SIGNALS

In order to examine the validity of the strategy for sensing described in Chapter 2, we attempted to measure artificial AE signals by using the proposed sensor. The sensor was attached to the center of an aluminum alloy plate (120 x 120 x 20 mm) with high vacuum silicone grease and a steel ball (ϕ10 mm, 4.2 g) was dropped from 40 mm height above the opposite side of the plate. The light transmitting in the optical fiber was provided by a DFB light source (Appointech, B1000; central wavelength: 1549 nm, spectral width: 0.4 nm, output power: 0 dBm) with an isolator avoiding the influences of the Fresnel reflection, and the signals of the interference light were recorded to a digital storage oscilloscope by the sampling rate of 1 μs via an O/E converter (Thorlabs, PDA10CF). The experiment replacing the conventional wide band type piezoelectric AE sensor (NF Corporation, AE-900S-WB) in the experimental setup was also conducted for the purpose of comparison with the results.

An example of the AE signal detected by the proposed Fabry-Perot interferometer type sensor is shown in Figure 5. It is found that the remarkable change in the amplitude is observed around the time of 150 μs. This fact implies that the proposed sensor could successfully detect the AE signal. Figure 6 shows result of the experiment using the piezoelectric sensor. It is found that there is a tendency of the waveform to change in a period of several hundreds μs after arrival of the initial motion of the AE wave. Similar behavior is also found in Figure 5 so that the proposed sensor could be used to examine the same phenomenon detected by the piezoelectric sensor. The amplitude of the waveform detected by the proposed sensor, however, is considerable low rather than that of the piezoelectric sensor. One of the reasons for low amplitude signals detected by the proposed sensor is due to the fact that the Fabry-Perot interferometer made of FBGs is only workable to the narrow bandwidth filtered light around the Bragg wavelength. Further discussion on improving sensitivity is required to apply the proposed sensor for monitoring AE associated with fracture. On the other hand, the Fabry-Perot interferometer is preferable from the viewpoint of sending stability due to fiber handling because the sensor has no reference fiber, while the Mach-Zehnder interferometer type sensor requires the reference fiber which should be fixed in order to avoid the vibration caused by either of AE signals and disturbance. Consequently, it is reasonable to conclude that the Fabry-Perot interferometer type sensor made by proposed method can improve usability of the interferometer type optical fiber AE sensors.

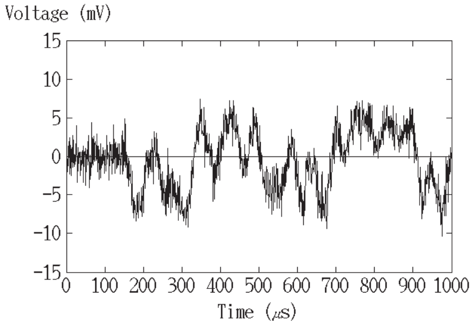


Figure 5: AE signal detected by the proposed Fabry-Perot interferometer type optical fiber sensor

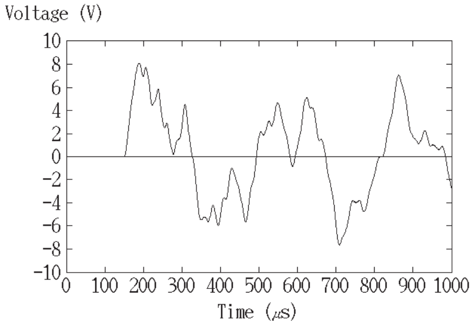


Figure 6: AE signal detected by the piezoelectric sensor

4 CONCLUSION

The Fabry-Perot interferometer type optical fiber AE sensor was proposed for the purpose of improvement the convenience in handling. The Fabry-Perot interferometer was made of a pair of FBGs and it was adhered to the inside of a cylindrical sensing block in order to detect the out-of-plane component of the displacement caused by AE waves and have no directivity. It was demonstrated that the proposed sensor could detect the artificial AE signals caused by dropping the steel ball form the result of the experiment comparing with the piezoelectric sensor.

REFERENCES

[1] Shiga, M., Suzuki, G., Yamada, M., Kitahara, M. and Niitsuma, H., (2002) "A Fiber-Optic Micro Sensor for AE Measurement Fabricated by Micromachining", *Progress in Acoustic Emission XI*, pp.152-159.

[2] Matsuo, T. and Takemoto, M., (2002) "Development of AE Monitoring System Using Optical Fibers", *Progress in Acoustic Emission XI*, pp.168-175.

[3] Duke, J.C., Jr., Cassino, C.D., Childers, B.A. and Prosser, W.H., (2003) "Characterization of an Extrinsic Fabry-Perot Interferometric Acoustic Emission Sensor", *Materials Evaluation*, Vol.61, No.8, pp.935-940.

[4] Ohsawa, I., Kageyama, K., Tsuchida, Y. and Kanai, M., (2003) "Development of a Novel Optical Fiber Sensor for AE Detection in Composites", *Journal of Acoustic Emission*, Vol.21, pp.176-186.

[5] Cho, H., Arai, R. and Takemoto, M., (2005) "Development of Stabilized and High Sensitive Optical Fiber Acoustic Emission System and Its Application", *Journal of Acoustic Emission*, Vol.23, pp.72-80.

[6] Yuki, H. and Mine, Y., (2006) "Simultaneous Measurement of Acoustic Emission and Strain Using a Hybrid Optical Fiber Sensor", *Progress in Acoustic Emission XIII*, pp.11-18.

[7] Yuki, H. and Kai, T., (2012) "Structure and Characteristics of the Mach-Zehnder Interferometer Type Optical Fiber AE Sensor with High Portability", *Journal of the Japanese Society for Non-Destructive Inspection*, Vol.61, No.9, pp.488-494 (in Japanese).

[8] Takuma, M., Hisada, S., Saitoh, K., Takahashi, Y., Kobayashi, Y., Kadono, A., Murata, A., Iwata, S. and Sasaki, T., (2014) "Acoustic Emission Measurement by Fiber Bragg Grating Glued to Cylindrical Sensor Holder", *Advances in Materials Science and Engineering*, Vol. 2014, Article ID 274071, doi:10.1155/2014/274071.

[9] Wu, Q., Yu, F., Okabe, Y. and Kobayashi, S., (2015) "Application of a Novel Optical Fiber Sensor to Detection of Acoustic Emissions by Various Damages in CFRP Laminates", *Smart Materials and Structures*, Vol.24, doi:10.1088/0964-1726/24/1/015011.