ABSTRACT

A fiber optic Bragg grating based acoustic emission sensor system is developed to provide on-line monitoring of cracks or leaks in reactor vessel head penetration of nuclear power plants. Various type of fiber Bragg grating sensor including the variable length of sensing part was fabricated and prototype sensor system was tested by using PZT pulser and pencil lead break sources. In this study, we developed a cantilever type fiber sensor to enhance the sensitivity and to resonant frequency control. Two types of sensor attachment were used. First, the fiber Bragg grating sensor was fully bonded to the surface using bonding agent. Second one is that one part of fiber was partially bonded to surface and the other part of fiber will be remained freely. The resonant frequency of the fiber Bragg grating sensor will depend on the length of sensing part. Various kinds of resonant type fiber Bragg grating acoustic emission sensors were developed. Also several efforts were done to enhance the sensitivity of FBG AE sensor, which include FBG spectrum optimization and electrical and optical noise reduction. Finally, based on the self-developed acquisition system, a series of tests demonstrate the ability of the developed fiber sensor system to detect a pencil lead break event and continuous leak signal.

Keywords: Acoustic emission, Fiber Bragg grating, Fiber optic sensor, Cracks and leaks, On-line monitoring

INTRODUCTION

We can evaluate the structural integrity by measuring the acoustic emission (AE) due to crack or leek. Acoustic emission has emerged as a powerful nondestructive tool to detect or monitor preexisting defects and leaks in the vessel structures. Conventional AE monitoring system utilizes piezo-type AE sensor (PZT sensor). PZT sensor has some excellent advantages such as easy handling, high signal to noise(S/N) ratio and so on. But the PZT sensor has following disadvantages; (1) inferior explosion or fire proof due to the piezoelectric effect, (2) low heat resistance due to the curie temperature of PZT, (3) limitation of sensor mounting only on smooth and flat surface, (4) heavy cable and monitoring system for multi-channel monitoring.[1] Newly developed fiber optic AE sensor has many advantages than conventional PZT AE sensor.

1) immune to electromagnetic noise and applicable to harsh environment
2) easy to install due to small size
3) can be multiplexed
4) can be used in high temperature (~ 400 °C : polyimide coating, ~ 700 °C : gold coating)[2-3]

These advantages make it possible to apply the fiber optic AE sensor to on-line monitoring of cracks or leaks in reactor vessel head penetration of nuclear power plants.

In this study, various type of fiber Bragg grating sensor including the variable length of sensing part was fabricated and prototype sensor system was tested by using PZT pulser and pencil lead break sources.

FBG SENSOR WORKING PRINCIPLE

A fiber-optic Bragg grating (FBG) is a permanent, periodic perturbation of the refractive index which is laterally exposed in the core of an optical fiber, extending over a limited length of the fiber as shown in Fig. 1[3]. Such a periodic structure acts as a filter for light traveling along the fiber line. It has the property of reflecting light in a predetermined range of wavelength centered around a peak wavelength.
value. External forces such as strain, pressure or a temperature change lead to changes in the grating period and in the effective refractive index. Consequently, the wavelength of the light reflected from the grating varies. By measuring the wavelength shift using a high resolution wavelength interrogation system, the Bragg gratings sensor can be used as strain or temperature sensors. But the maximum speed of conventional wavelength interrogation system is about 200 ~ 2000 Hz. So it is suitable to static sensing of strain and temperature, but it can not be used to dynamic sensing such as acoustic wave detection [3].

For the acoustic wave detection we need new fast interrogation system. The working principle of fiber optic sensor using FBG (Fiber Bragg Grating) was shown in Fig. 2. By using a tunable laser source (TLS), narrow band laser source was tuned to mid-reflection wavelength of the FBG. The light was reflected from the FBG and then entered a photo detector. The change in the pitch of the FBG caused by acoustic wave was demodulated by the reflected intensity variation. In this case, there is no need of wavelength interrogation system, so this fiber optic FBG sensor can be used for acousto-ultrasonic measurement. This basic principle of this demodulation technique has already been introduced[4]. But for the practical application of this fiber optic FBG AE sensor, we need to develop high sensitive sensor head comparable to conventional PZT sensor.

Figure 1 - Schematic of FBG (Fiber Bragg Grating)
SENSITIVITY ENHANCEMENT OF FIBER OPTIC AE SENSOR

We developed two types of fiber optic FBG AE sensors as shown in Fig. 3. In this study, we developed a cantilever type fiber sensor to enhance the sensitivity and to resonant frequency control. Two types of sensor attachment were used. First, the fiber Bragg grating sensor was attached fully to the surface using bonding agent. Second one is that one part of fiber was attached to the surface partly by bonding and the other part of fiber will be act as a cantilever. That is, the resonant frequency of the fiber Bragg grating sensor will depend on the length of sensing part as shown in following equation

$$f_i = c / 4l$$  \hspace{1cm} (1)

Fig. 4 shows the fiber optic AE sensor frequency spectrum acquired from pencil lead break test. This figure shows the resonance frequency was well coincide to the designed value. Through this resonance design of fiber optic AE sensor, we can enhance the sensitivity at the desired frequency range.
EXPERIMENT

The experimental setup for acoustic wave detection using fiber optic AE sensor was shown in Fig. 5. The light which wave length was tuned to mid-reflection point of FBG spectrum was introduced to FBG AE sensor head via circulator and the reflected light from FBG was converted to electrical signal using amplified photo detector. Two conventional PZT AE sensors (60 kHz, 300 kHz) were used for comparison. The acoustic wave sources were pencil lead break and PZT sine pulse.

Figure 4 - Change of resonance frequency by length of grating

Figure 5 - Schematic diagram of experimental setup
EXPERIMENTAL RESULTS

Acoustic waveforms generated by pencil lead break were measured using cantilever type fiber optic AE sensor and conventional PZT AE sensors and they were shown in Fig. 6. These transient waveform characteristics were used to simulate crack initiation signal. The cantilever type fiber optic AE sensors which have 60 kHz and 300 kHz resonance frequency were compared to conventional PZT AE sensors which have the same resonance frequency. The 300 kHz resonance frequency fiber optic AE sensor shows more sensitive high frequency waveform.

Figure 6 - Pencil break signal acquired by cantilever type FBG AE sensor

Figure 7 - Pencil break signal acquired by bonded type FBG AE sensor
Acoustic waveforms generated by pencil lead break were measured using bonded type fiber optic AE sensor and they were shown in Fig. 7. The bonded type fiber optic AE sensor showed low frequency characteristics and 10 mm FBG grating showed high sensitivity because of their stiff slope of FBG spectrum.

Acoustic waveforms generated by PZT pulser were measured using fiber optic AE sensor and conventional PZT AE sensor and they were shown in Fig. 8. These continuous waveform characteristics were used to simulate leak signal. The acoustic waveforms were generated by PZT pulser with 60, 100, 200, 300 kHz single sine pulse and measured by 60 kHz resonance frequency fiber optic AE sensor. Conventional PZT AE sensors can measure waveform only near their resonance frequency, but fiber optic AE sensor can measure all tested frequency range waveform. This shows fiber optic AE sensor has more broadband characteristics than conventional PZT AE sensor.

The fiber optic AE sensor signal passed band-pass filter with the same frequency range of conventional PZT AE sensor preamplifier band-pass filter were shown in Fig. 9. The FBG sensor signal showed very similar waveform compared to the conventional AE sensor after passing band-passing filter. So, the fiber optic AE sensor can have similar characteristics of conventional PZT AE sensor by signal processing using proper filter.

Figure 8 - PZT pulser signal acquired by FBG and PZT AE sensor by changing frequency
CONCLUSIONS

Sensitivity enhancement of fiber optic AE sensor was done through resonance design of sensor. Through pencil break test, we found that the bonded type FBG sensor shows broadband spectrum and longer FBG grating shows high sensitivity. Also, the cantilever type sensor shows high sensitive resonance frequency spectrum as designed. Through PZT sine pulse test, we found that fiber optic AE sensor shows more broadband spectrum than conventional PZT AE sensor even in case of resonance type. Fiber optic AE sensor shows very similar waveform to conventional PZT AE sensor if applied band-pass filter.

REFERENCES

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Figure 9 - Pencil break signal acquired by FBG and PZT AE sensor with band-pass filter