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Comparison of FBG sensors and thermocouples for measurement of temperature rise by exposure to ultrasound

超音波照射による FBG センサーと熱電対の温度上昇測定の比較

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1. Introduction

In recent years, acoustic radiation force impulse (ARFI) has attracted attention in the field of ultrasonic diagnosis. In the ARFI technology, the focused and long-duration ultrasounic pulses are used to produce microdisplacement of focused area in soft tissues and to produce shear elastic waves. A conventional ultrasonic diagnostic equipment is considered as noninvasive one compared with the other medical imaging system such as X-ray CT. However, since in the ARFI technology large amplitude waves of durations of several hundred of microseconds or more are used, there is concern about temperature increases in the exposed area of the biological tissues. Thus, it is important for the safety concern to measure temperature rise in the biological tissues exposure to ultrasound. For the measurement of temperature rise thermocouples are genrally used in the biological tissues exposure to ultrasound. Due to viscous heating, the tempeture rise is more than that by the ultrasonic exposure [1].

In this study, we propose a method for the measurement of temperature changes by exposure to ultrasound using optical fiber Bragg grating (FBG) sensors. Using ultraviolet light transmitted along an optical fiber, bands with a different refractive index to the main fiber can be created at equal intervals in the fiber, which act as a diffraction grating so that light of specific wavelengths is reflected. Such a grating is referred to as an FBG, and is often used in sensors since the reflected Bragg wavelength is sensitive to both strain and temperature. By exposure to ultrasound, the refractive index of the FBG changes due to the sound pressure and temperature, thus leading to fluctuations in the Bragg wavelength. However, since the frequencies of fluctuations caused by sound pressure and temperature variations are very different, they can be easily separated by filtering.

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2. Principles

When an FBG is exposed to a coherent light, the light component of the Bragg wavelength λ_B is reflected, and this component is given by[2]

$$\lambda_B = 2n\Lambda \qquad (1)$$

where n is the refrective index in the core and Λ is the grating period. The Bragg wavelength changes linearly with strain produced by an external force.

When an FBG is exposed to the ultrasound wave, λ_B changes due to changes in n and Λ resulting from the strain produced by thermal expansion of the FBG and sound pressure. Whereas temperature changes cause a gradual shiht in λ_B, fluctuations due to sound pressure occur at ultrasound frequencies. Since the difference between these frequencies can be in the high MHz range, when the optical signals are converted into elecrical signals, temperature change can be measured using low pass filter.

3. Experiment

3.1 Temperature rise by heater

Figure 1 shows the experimental setup for measurement of temperature change by a 0.1 mm copper-constantan (T-type) wire thermocouple (Chino-Corp.) and a 0.25 mm of diameter 1 mm long glass FBG (Shinko Electric Wire Corp.). The FBG and the thermocouple were immersed in a water tank. The water temperature was varied from 36 to 42 °C in 1°C steps by heater. When the temperature was measured by the FBG, reflected light from the FBG was transformed into electric signal and measured electric output change caused by temperature change. Temperature detection sensitivity of the FBG was 40 mV/˚C.

Figure 2 shows the relation of temperature rise to temperature measured by FBG compared with the thermocouples results. Maximum difference in temperature between them was only about 0.2 ˚C. Therefore FBG can measure temperature rise almost the same actuary with thermocouples.

3.2 Temperature rise by exposure to ultrasound

Using FBG sensor and thermocouples, temperature rise by ultrasound exposure was measured. The input conditions were a frequency of 2 MHz, continuous wave, exposure time of 15 s, and an input voltage of 24 V_{pp} amplified by 50 dB with a power amplifier. Signals were applied to a concave transducer with a focal length of 35 mm.

Figure 3 shows the comparison of FBG and thermocouples for measurement temperature rise by exposure to ultrasound in water. In the thermocouples, temperature rise occurred at the same time as the ultrasonic irradiation, and it became diminished along with the stop of the ultrasonic irradiation. This temperature rise is due to viscous heating caused by viscous friction with water. On the other hand, the temperature rise due to ultrasound irradiation in FBG sensor was small compared to the thermocouple. Viscous heating is caused by relative motion between the thermocouple or the FBG and the surrounding medium at ultrasound field. The amount of the relative motion is determined by the difference in density of the surrounding medium. In the glass which is material of the FBG, the difference between the density of the water is less than that of copper which is material of the thermocouple. Therefore, the amount of the temperature rise caused by viscous heating in FBG was less than that of thermocouples. Thus FBG sensor can be a temperature sensor that influence of viscous heating by ultrasonic exposure is less than that of the thermocouple.

4. Conclusion

In this study, we propose a method for simultaneous measurement of temperature changes by exposure to ultrasound using an optical FBG sensor. Maximum difference in temperature was only about 0.2 ˚C. As a result, temperature rise measured by the FBG sensor agree with the values measured by the thermocouples. The values of temperature rise in the water exposure to ultrasound measured by FBG were much smaller than the values measured by the thermocouple. FBG sensor can be a temperature sensor whose influence of viscous heating by exposure to ultrasound is ignorable for this purpose.

Acknowledgements

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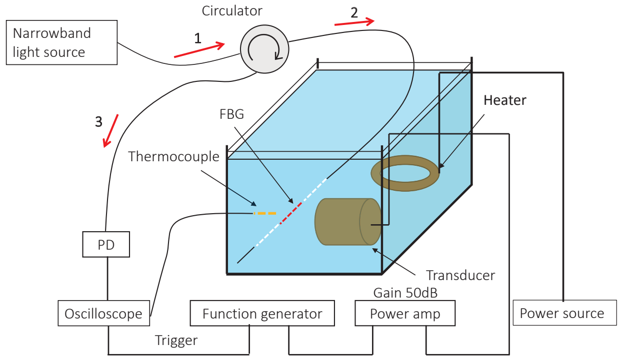

Fig. 1 Experimental system for measurement of temperature change by thermocouple and FBG.

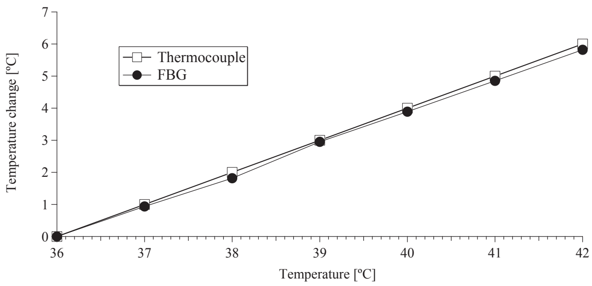

Fig. 2 Comparison of FBG and thermocouples of temperature change.

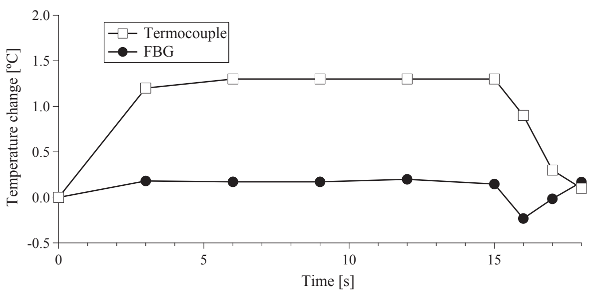

Fig. 3 Comparison of measured temperature rise by FBG sensors and thermocouples in water by exposure to ultrasound.

Reference

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