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FBG-based vibration measurement of rotating structure using optical fiber rotary joint

光ファイバロータリジョイントを用いた FBG による回転体の振動計測

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1. Introduction

Recently, fiber-optic sensing technology has played an important role in monitoring systems because of its many advantages such as long-distance measurement, highly sensitive operation, immunity to electromagnetic induction, and flexible arrangement. Among the various fiber sensors, grating-based fiber sensors that utilize fiber Bragg gratings (FBGs) as sensing elements are very attractive for dynamic measurements (e.g., mechanical vibration and sound pressure) as well as static measurements (e.g., strain and temperature) since they have practical advantages of compact size, high compatibility with transmission fibers, and ease of multiplexing[1]. In these circumstances, we have demonstrated various FBG sensors based on intensity modulation scheme, which enables the high-frequency vibration measurement with high precision[2]. Although various FBG sensors have been proposed for use in diagnosing or assessing the structural integrity and the surrounding environment, they have not yet been applied to rotating structure especially for dynamical measurement. In the present work, we constructed an intensity-based FBG sensor for vibration measurement of rotating structure using an optical fiber rotary joint (OFRJ) and demonstrated the performance principle.

2. Operation principle

In the FBG vibration sensors using intensity modulation scheme, a narrow-band optical source is used and its wavelength is tuned to a slope of the FBG reflection (or transmission) spectrum curve. The sensor output is obtained from the optical intensity of the partially reflected (or transmitted) light at the FBG; the strain-induced Bragg wavelength shift is extracted from the variation of the optical intensity from the sensing FBG. In such FBG sensors, therefore, stable optical sources or intensity compensation techniques are required for the highly precise operation of the sensors. Since the FBG sensor using an OFRJ would be likely to be suffered from the variation of insertion loss of the joint, we thus introduced reference FBG sensor to compensate the intensity variation due to the rotating joint.

Figure 1 shows the conceptual scheme of an FBG vibration sensor in which two FBG sensors (FBG_{S1} and FBG_{S2}) are serially arrayed for the sensing and reference by using wavelength division multiplexing (WDM) technique[3]. For an optical source, a dual-wavelength tunable fiber laser is fabricated by employing a semiconductor optical amplifier (SOA) as a gain medium and two FBGs (FBG_{L1} and FBG_{L2}) as wavelength selectable coupling mirrors as is shown in the dashed square in Fig.1. The two wavelength components, λ_1 and λ_2, serve optical sources for the FBG sensors. The respective oscillation wavelength λ_1 (or λ_2) is tuned to the slope of the reflection spectrum curve of FBG_{S1} (or FBG_{S2}) by adjusting the applying strain to PZT_1 (or PZT_2) for FBG_{L1} (or FBG_{L2}). The

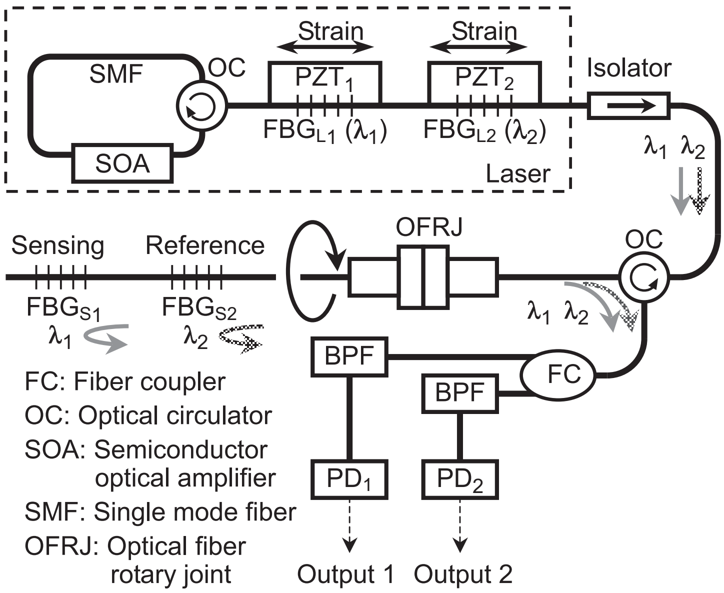

Fig. 1 Conceptual scheme of experimental setup.

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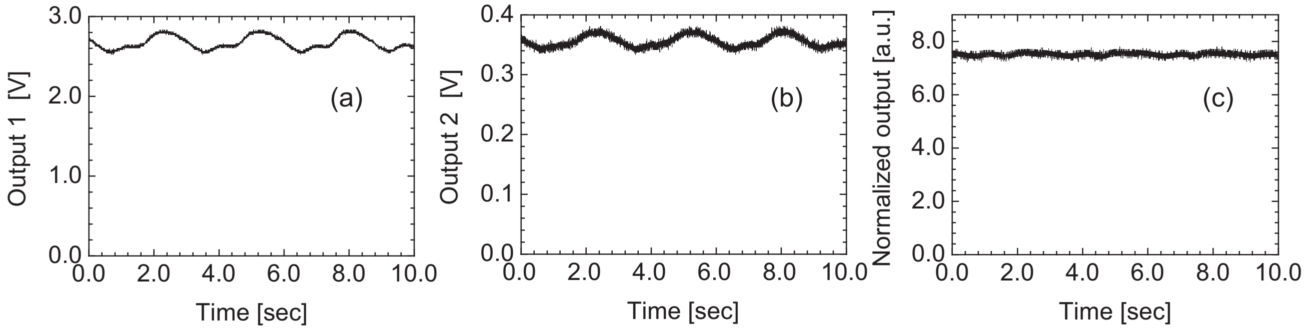

Fig. 2 Outputs for signal (a) and reference (b), compensated output signal (c).

optical wave from the laser enters into the sensing and reference FBGs after passing through the optical circulator (OC) and OFRJ. In this configuration, λ_2 component partially reflected at FBG_{S2} is detected at the photodetector PD_2. On the other hand, λ_1 component is totally transmitted through FBG_{S1} and is partially reflected at FBG_{S1} to be coupled into PD_1. The reference signal from PD_2 is used for the compensation of the intensity variation due to the joint.

3. Experiment and Results

Firstly, performance principle of the intensity compensation of the sensor output using reference signal was demonstrated; FBG_{S1} and FBG_{S2} were fixed on a disk that was rotated at a constant angular velocity. Typical output signals from PD_1 and PD_2 are shown in **Fig. 2 (a)** and **2 (b),** respectively. As can be seen from the figures, the output signals are fluctuated periodically. This is because that the insertion loss of the OFRJ depends on rotation angle. Since both the signals vary in the same manner, the output compensation can achieved by dividing output 1 with output 2 as shown in **Fig 2 (c)**.

The demonstration of the vibration measurement was performed in such a way that FBG_{S1} was glue to a cantilever beam that was put on the rotating disk and was exerted periodical impact with a constant rotation. **Figure 3 (a)** and **3 (b)** shows the sensor output with and without rotation, respectively. Although the waveforms are different from each other, the frequencies of the outputs are the same and correspond to the frequency of the fundamental mode of the cantilever beam.

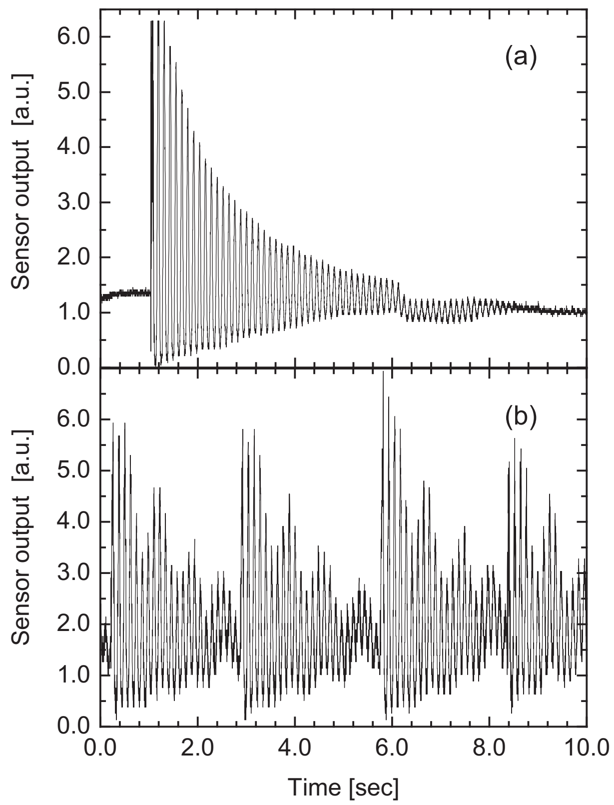

Fig. 3 Sensor outputs with (a) and without (b) rotation.

4. Concluding Remarks

In the present work, an intensity-based FBG sensor was constructed for use in vibration measurement of rotating structure using an OFRJ. By introducing an additional reference FBG sensor, the compensation the intensity variation due to the insertion loss of OFRJ can be realized. In the experiment, the performance principle of the sensor system was successfully demonstrated.

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