Response comparison of FBG sensor, strain gage, and piezo-electric accelerometer in an aluminum cantilever beam shock load

Shintaro Fukumoto ¹, Tomio Nakajima ¹

¹ IHI Inspection & Instrumentation Co., Ltd., 6-17, Fukuura 2-chome, Kanazawa-ku, Yokohama-city, Kanagawa, Japan
s_fukumoto@iic.ihi.co.jp

Abstract
Aluminum-alloy-cantilever hammering tests were carried out using fiber Bragg grating (FBG) sensors, and strain-gages piezo-electric accelerometers to evaluate vibration measurement performance at the fixed end. Although accelerometers are used in vibration tests generally, it is difficult to measure vibration at the fixed end of the cantilever because of short arm lengths. However, it is expected that adopting FBG sensors makes measuring dynamic strains at the fixed end easy. The tests results show that FBG sensors can measure wider frequency-range vibrations than those in the cases using accelerometers. Moreover, it was easy to compare the frequency analysis results of FBG sensor signals and the FEM analysis results. These results show that it is effective to measure vibrations at the fixed end of cantilevers using FBG sensors.

Keywords: Optical fiber sensor, Vibration analysis, FBG sensors, Nondestructive inspection

1. INTRODUCTION
In recent years, FBG sensors are widely used in such as civil engineering and construction field and the aerospace field. FBG sensors can measure both strain and temperature change. When applying the FBG sensor to the structure, it is often used as a strain sensor. In consideration of the mechanical properties of the FBG sensor, it has been reported to be possible to measure the vibration and shock [1-2].

In general, when an external force is applied to the beam structure, the fixed end is the occurrence point of maximum stress. There is a starting point of fracture. In this position, by measuring strain and acceleration at the same time, we considered that it is possible to soundness evaluation of the structure. Further, in the measurement, care must be taken to the electrical effects of the use environment and other equipment. Strain gauges and accelerometers are susceptible to electrical influence, to use a filter to remove the noise of the vibration waveform (low-pass, and high pass filter). Therefore, measurable frequency range of the strain gauges and accelerometers are limited. On the other hand, FBG sensors are not subjected to noise of the electromagnetic induction, and not necessary filter. Therefore, FBG sensor is capable of a wide range of measurement. Based on the above, in this study, we focused on the vibration at fixed end neighborhood of the cantilever. And aluminum-alloy-cantilever hammering tests were carried out using fiber Bragg grating (FBG) sensors, piezo-electric accelerometers and strain-gages to evaluate vibration measurement performance at the fixed end.
2. EXPERIMENTAL

High-speed strain measurement system for FBG sensors [3] was used to measure dynamic strain during hammering tests. The system has adopted the method that had been proposed by Davis and Kersey in 1994 [4] and has been re-developed by Tsuda and Lee [5].

We compared the vibration measurement performance at the fixed end neighborhood by the FBG sensors, piezo-electric accelerometers and strain-gages using a cantilever. Vibration applied was carried out by hammering shock.

In this study, two types of test pieces were used. The dimension of the test piece 1 is as follows: H 4 mm × W 70 mm × L 165 mm, the test piece 2 is as follows: H 4 mm × W 75 mm × L 400 mm. The material of each test pieces is aluminum alloy (AL7075-T6).

FBG sensors, strain gauges, and the accelerometers were affixed to each of the test piece. Figure 1 shows the test piece 1 setup, Figure 2 shows the test piece 2 setup. The FBG sensor, strain gauges, and the accelerometer placed on the Point 1, and 2 of the test piece 1. The FBG sensor, strain gauges, and the accelerometer placed on the Point 1, and 2 of the test piece 1. The FBG sensor and strain gauges placed on the Point 1, 2, and 3, the accelerometer placed on the only Point 1 of the test piece 2. In this test, to calculate the natural frequency at a place other than the fixed end, to confirm whether there is no difference in each value. Strain gauges were used KFG-5-120-C1-23 (Kyowa Electronic Instruments Co., Ltd.). Accelerometers in the test piece 1 was used 2222C (ENDEVCO), in the test piece 2 was used AS-50B (Kyowa Electronic Instruments Co., Ltd.). For FBG sensors, each test piece was measured multipoint a single optical fiber. Figure 3 shows overall view of the test piece 2, and each sensor installation conditions of fixed end neighborhood.

![Figure 1: Test piece 1 setup](image1)

![Figure 2: Test piece 2 setup](image2)
3. RESULTS

3.1 STRAIN WAVEFORMS AND ACCELERATION WAVEFORMS

Figure 4 shows each of signal waveforms in the test piece1 Point1, Figure 5 shows it in the test piece2 Point1. In the test piece1, sampling frequency was 500 kHz. In the test piece2, it was 5000 Hz. Sampling frequency is 1 second measurement points. Frequency band in the frequency analysis become half of the sampling frequency.

Strain measurement results of the test piece1 were ±100με by FBG sensor and strain gage, and acceleration measurement result was 5000m/s² by the accelerometer (2222C). Strain measurement results of the test piece2 were ±40με by FBG sensor and strain gage, and acceleration measurement result was 50m/s² by the accelerometer (AS-50B). Based on these results it was confirmed that FBG sensors are capable of strain measurement equivalent to strain gauge.

Figure 3: Overall view of the test piece 2, and each sensor installation conditions of fixed end neighborhood

Figure 4: Each sensor signal waveform in the test piece 1 of Point1

Figure 5: Each sensor signal waveform in the test piece 2 of Point1
3.2 FREQUENCY ANALYSIS

Figure 6 shows each of signal waveforms in the test piece1 Point1. Figure 7 shows it in the test piece2 Point1. In the Figure 6, frequency range is 1 Hz~250 kHz. In the Figure 7, it was frequency range is 0.1 Hz~2.5 kHz. Each peak shows the natural frequency of vibration bending. Frequency analysis results of FBG sensors were obtained the natural frequency from 1st~ 6th order. However, frequency analysis results of strain gages were obtained only 1st order natural frequency, because it is difficult to distinguish between noise and the natural frequency.

Based on these results it was confirmed that the FBG sensors are obtained the natural frequency of 15 Hz~100 kHz, and it is possible to a wide range of vibration measurement than the strain gauges and accelerometers. Further, natural frequencies at places other than the fixed end neighborhood also became the same results as the fixed end neighborhood.

4. FEM

FEM models of each test piece were created, eigenvalue analyses were done with ABAQUS. The model is 4-node quadrilateral elements, the minimum mesh is 1 mm. Figure 8 shows FEM model of the sixth natural frequency in the test piece1 as eigenvalue analysis example. The color change is a displacement distribution.

Table 1 shows comparison of the natural frequency obtained by the FEM analysis model and FBG sensor measurements in the test piece 1, Table 2 shows it in the test piece 2. In natural frequency of up to sixth order, the error of eigenvalue analyses and FBG sensor measurements was less than 2%.

Based on these results it was considered that FBG sensor measurements are sufficiently reliable. Each natural frequency calculated from physical properties of the specimens was similar to the results of eigenvalue analysis.
5. CONCLUSIONS

In order to evaluate vibration measurement performance at the fixed end neighborhood of the cantilevers, hammering tests were carried out using FBG sensors, piezo-electric accelerometers and strain-gages. FBG sensors are capable of strain measurement equivalent to strain gauge. In addition, the compatibility of experimental value by the FBG sensor and analysis value by FEM was confirmed until the sixth-order natural frequency. These results show that it is effective to measure vibrations at the fixed ends neighborhood of cantilevers using FBG sensors.

Table 1: comparison of the natural frequency obtained by the FEM analysis model and FBG sensor measurements in the test piece 1

<table>
<thead>
<tr>
<th>Mode</th>
<th>FEM(Hz)</th>
<th>FBG sensor Frequency spectrum(Hz)</th>
<th>Error(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>118</td>
<td>117</td>
<td>0.85</td>
</tr>
<tr>
<td>2</td>
<td>707</td>
<td>704</td>
<td>0.43</td>
</tr>
<tr>
<td>3</td>
<td>2033</td>
<td>2024</td>
<td>0.44</td>
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<tr>
<td>4</td>
<td>3940</td>
<td>3924</td>
<td>0.41</td>
</tr>
<tr>
<td>5</td>
<td>7409</td>
<td>7404</td>
<td>0.07</td>
</tr>
<tr>
<td>6</td>
<td>9770</td>
<td>9733</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Table 2: comparison of the natural frequency obtained by the FEM analysis model and FBG sensor measurements in the test piece 2

<table>
<thead>
<tr>
<th>Mode</th>
<th>FEM(Hz)</th>
<th>FBG sensor Frequency spectrum(Hz)</th>
<th>Error(%)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td>6</td>
<td>1321</td>
<td>1327</td>
<td>0.45</td>
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</table>

Figure 8: FEM model of the sixth natural frequency in the test piece 1
REFERENCES


