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Damage detection of damaged beam using impedance load SAW sensor
インピーダンス負荷 SAW センサを用いた片持ち梁の損傷検知

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1. Introduction

In recent years, the aging such as bridges maintained in 1960's is a problem and developments of a health monitoring sensor for those structures are required. We have proposed the new health monitoring sensor combining a surface acoustic wave (SAW) device and a pressure sensor, which are called impedance loaded SAW sensor[1]. Wireless and battery-less sensing system is realized with the impedance-loaded SAW sensor. This is advantage to use SAW device. In this paper, vibration measurements of the damaged beam (PET resin plate) were carried out using the pressure sensor loaded SAW sensor. The beams had a hole to simulate damaged structures. In order to use the impedance-loaded SAW sensor as a sensor for health monitoring, we discussed optimum parameters for the health monitoring from the obtained results, such as natural and 2nd frequencies, attenuation coefficient and so far.

2. Principle of impedance load SAW sensor

Fig. 1 shows the schematic illustration of the impedance load SAW sensor. The SAW is excited when a high frequency signal is applied to the input interdigital transducer (IDT) on the piezoelectric substrate. The SAW propagating on the piezoelectric substrate is reflected by the reflectors and converted into the high frequency signal again by the IDT. The characteristic of the reflected SAW depends on the external impedance connected to the reflector. Therefore, by connecting an impedance change type sensor to the reflector, it is possible to measure the physical quantity from the reflected response of the SAW. In this paper, to monitor a strain change, the pressure sensor is connected to the reflector.

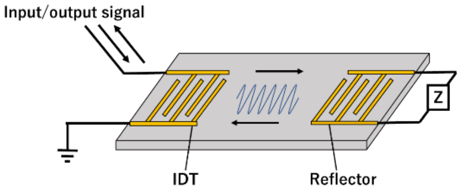

Fig. 1 Schematic illustration of the impedance load SAW sensor.

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3. Vibration evaluation parameters

In this paper, a PET resin plate was used as a beam. Measurement system and measurement method of vibration are the same shown in Ref. 1. As damages were applied to the beam, a hole was made near the fixing part of the PET resin plate (see **Fig. 2**). **Figs. 3 and 4** show time response of the vibration and the frequency response obtained by the Fast Fourier Transform (FFT), respectively. Four parameters were obtained to evaluate the damage of the beam. The natural frequency was measured as one of the evaluation parameters. The second parameter was the attenuation coefficient obtained from the envelope of the time response in Fig. 3. The attenuation coefficient $\boldsymbol{c}$ was determined form curve fitting of the time response using the exponential function $\boldsymbol{y=a+b\times exp(cx)}$. In this paper, we focused on the 2nd harmonic frequency as shown in Fig. 4. The reason why the second harmonic wave appears is as shown in Ref. 1. The 2nd harmonic frequency was the third parameter. Furthermore, the peak ratio between the natural and 2nd harmonic frequencies was evaluated as the fourth parameter.

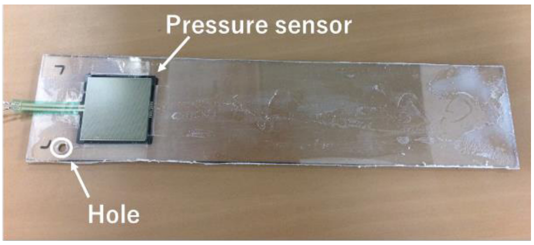

Fig. 2 PET resin plate with a hole.

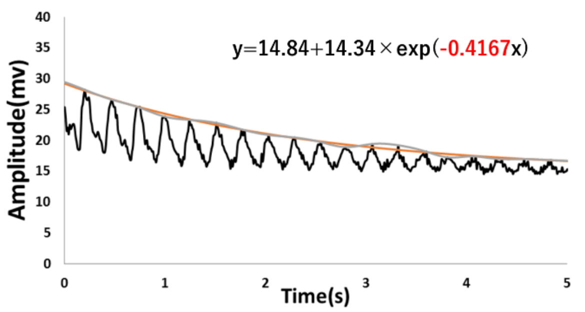

Fig. 3 Time response.

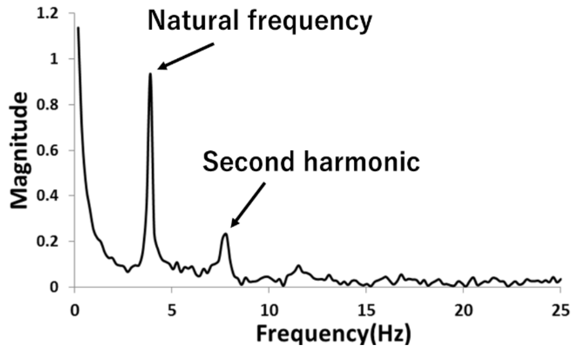

Fig. 4 The result of FFT.

4. Results and discussions

As the PET resin plate with thickness of 1.5 mm was put on the top the other, total thickness of the beam used was 3 mm. **Fig. 5** shows the cross section of the damaged beam used. First, a hole was drilled to a depth of 1.5 mm from the top surface (upper PET plate). Hole diameter was varied from 1.1 to 6 mm. **Table. 1** shows the measurement results of the four parameters. Then, the other PET was also drilled. The results are summarized in **Table 2.** The measurements were performed 10 times for each pattern. The average values with standard deviation are shown in the tables. 1 and 2.

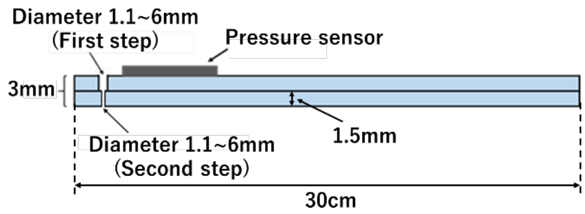

Fig.5 Cross section of damaged PET resin plate

Table 1 Measurement results(Hole depth 1.5 mm)

Diameter(mm)	Natural frequency(Hz)	Second harmonic frequency(Hz)	Peak ratio	Attenuation coefficient
0	8.13±0.17	Unmeasurable	Unmeasurable	−1.3758±0.1383
1.1	7.55±0.09	15.21±0.06	2.270±0.223	−0.9303±0.0728
2	7.81±0	15.53±0.10	2.071±0.254	−0.8083±0.0859
3	7.65±0.12	15.33±0.24	2.238±0.150	−0.7184±0.0591
4	7.61±0	15.37±0.09	2.230±0.291	−0.7630±0.0563
5	7.61±0	15.35±0.10	2.230±0.350	−0.7666±0.0366
6	7.65±0.12	15.47±0.19	2.101±0.199	−0.7656±0.0588

Table 2 Measurement results (2nd step)

Diameter(mm) (after the depth 1.5mm)	Natural frequency(Hz)	Second harmonic frequency(Hz)	Peak ratio	Attenuation coefficient
1.1	7.61±0	15.27±0.08	1.928±0.233	-0.6410±0.0689
2	7.57±0.08	15.11±0.10	1.720±0.239	-0.7827±0.0758
3	7.44±0.06	15.03±0.09	1.785±0.174	-0.7669±0.0540
4	7.57±0.08	15.21±0.11	1.793±0.211	-0.7284±0.0739
5	7.50±0.09	15.17±0.09	1.851±0.292	-0.7183±0.1055
6	7.44±0.06	15.07±0.08	1.728±0.167	-0.6878±0.0867

Whereas the natural frequency in Tables 1 and 2 are fluctuated. It has a tendency to decrease. For the 2nd harmonic frequency, the value goes up and down throughout and unidirectional change was not observed. As for the peak ratio, although there are fluctuated, the value became smaller as the load became larger. Before and after penetrating the hole, a slight change in the value was obtained. The graph showing the variation of the peak ratio with respect to the load change is shown in **Fig. 6**. As for the attenuation coefficient, the value became larger as the load became larger and it was confirmed that the value converged to an almost constant value after the diameter of 3 mm. The graph showing the variation of the attenuation coefficient with respect to the load change is shown in **Fig. 7**.

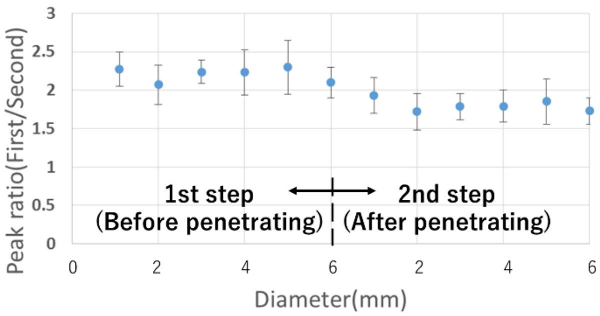

Fig. 6 Peak ratio variation.

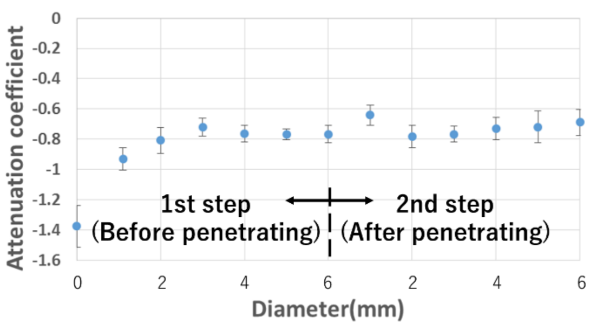

Fig. 7 Attenuation coefficient variation.

5. Conclusion

We measured the change in vibration when a hole was drilled in the thick beam and change the depth and diameter, and estimated the optimum parameter for damage detection. The results indicate that the damage of the beam can be determined from three parameters of natural frequency, peak ratio and attenuation coefficient. In particular, since the peak ratio changes before and after penetrating the hole, it will be possible to detect the hole depth. In future work, we will measure the vibration at different load conditions and at both end fixed beam simulating the actual bridge to confirm the reliability of the damage detection parameter.

References

1. M. Oishi, et al: Jpn. J. Appl. Phys. 55, 07KD06 (2016).