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Non-destructive testing of T-shaped metal object by considering vibration mode

振動モードに着目したT字型金属部材の非破壊検査

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1. Introduction

Non-destructive testing (NDT) of a mechnical part is commonly conducted with pulse-echo method using MHz ultrasonic waves [1]. The MHz ultrasonic waves propagate in a narrow beam and provide high spatial resolution both in depth and transverse directions. However, it is a time-consuming task to complete the test because it is required to scan the position of the transducer to inspect whole region of the object. In the case that target defect is located in shadow region in a complicated structure, it is difficult to detect the defect with the MHz pulse-echo method.

One of the authors tried to measure liquid volume in a cylinder tank by utilizing the resonant modes of the tank [2][3]. In this study, the authors attempt to utilize the resonant modes of the structure of the speimen for NDT. The resonant frequencies are sensitive to the defect, which locates in the place of high vibration strain. Being based on the observation of the variation of the resonant frequencies over a wide frequency range, existance of defect can be detected through only one time of measurement. In addition, the location of the defect is possibly determined with the help of modal analysis of the structure. A trial application of this method to a T-shaped structure is carried out in this report.

2. Principle of NDT method and Sensor Head

A sensor head consisting of a back mass, a piezoelectric ceramic element, and a semi-sphere lens is attached to the specimen as illustrated in **Fig. 1**. Here, we choose a 'T-shaped' metal specimen as an example of complicated shape. The transducer is excited with a continuous sinusoidal source, and the frequency is swept over the required range. Frequencies exhibiting peaks in the admittance (the ratio of the current to the voltage) are recorded in the measurement.

Fig. 2 shows the practical structure of the sensor head. A multilayered piezoelectric actuator 4×4 mm^2 in cross section and 5 mm in height was used. A steel screw was bonded on the rear surface of the actuator as the back mass. A semi-sphere glass lens was bonded at the other surface to reduce the contacting area on the specimen. The semi-sphere shape provides a freedom in the angle accuracy when one attaches the sensor head to the specimen. In the experiments, an impedance analyzer (Agilent 4294A) was used to obtain the frequency response of the sensor head.

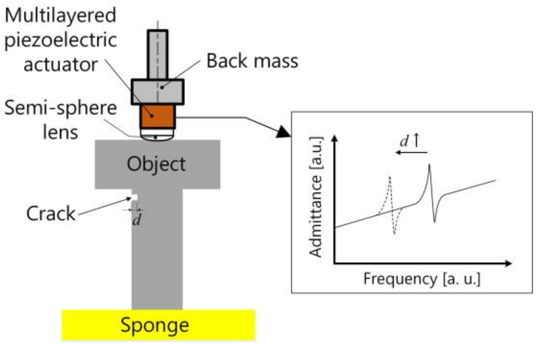

Fig. 1 Measurement setup of the proposed NDT

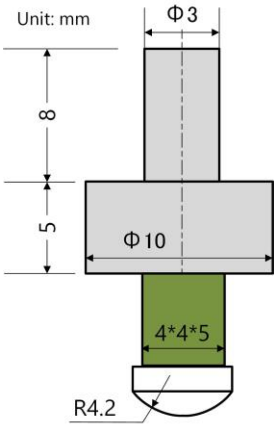

Fig. 2 Sensor head configuration.

3. Modal Analysis of T-shaped Specimen

A T-shaped stainless steel object depicted in **Fig. 3** was tested as a specimen. Here, modal analysis was conducted for this specimen without crack in the frequency range from 20 to 60 kHz through finite element analysis (FEA). Ten eigen modes have been found in this frequency range, but

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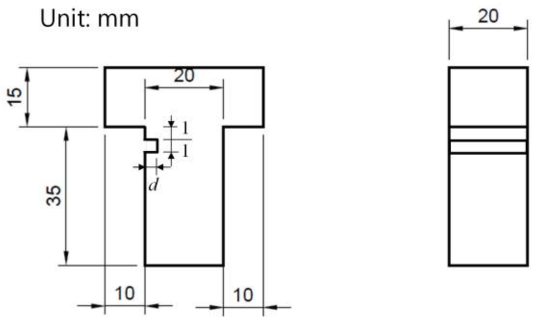

Fig. 3 T-shaped specimen. A crack is created at one of the inner corners of the 'T.'

seven of them were torsional and asymmetric or out-of-plane bending modes that can hardly be driven using the sensor head attached to the center of the top surface. Three of the modal shapes at a) 34.934, b) 50.547 and c) 64.334 kHz, which are able to be efficiently excited, are shown in **Fig. 4**. The vibration stress is indicated with color map in the figure. At 34.934 kHz, the horizontal bar of the 'T' vibrates in bending mode. The longitudinal mode along the vertical direction appears at 50.547 kHz. The mode at 64.334 kHz is mainly horizontally longitudinal one as observed from the simulation results.

4. Experiments

We carried out measurement under the same configuration as the FEA described in the former section. The admittance was measured at the electrodes of the piezoelectric actuator attached against the top surface of the T-shaped sample. The crack was created intentionally near the inner corner as shown in **Fig. 3**. The depth of the crack was changed.

In **Fig. 5**, the resonant frequencies of the three target modes shown in **Fig. 4** are plotted as functions of the depth of the crack. The FEA results are shown in curves, while the measured results of the resonant-frequency shift corresponding to the vibration mode at around 50.5 kHz is shown as the black circles. As predicted, clear frequency shifts were found with the existence of defect. The down shift increased as the crack became deeper.

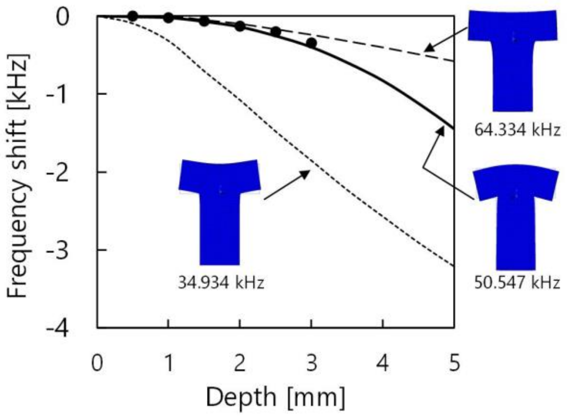

Fig. 5 Resonant frequencies as functions of crack depth. The FEA results are indicated with curves while the measured one with black dots.

5. Summary

Instead of pulse-echo inspection using MHz ultrasonic waves, the resonant frequencies of the specimen have been studied as the crack depth changes. With single point measurement using a piezoelectric actuator, the crack was successfully detected from the resonant frequency shift. The effectiveness of this method were validated by FEA. To utilize more sensitive modes, efficient excitation method need to be developed. Besides, location of the crack will be found by using the combination of several modes.

References

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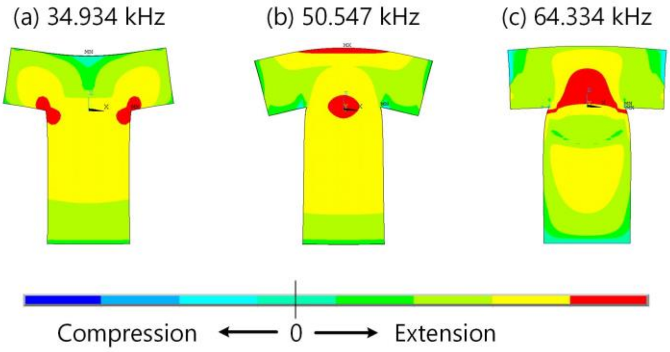
(a) 34.934 kHz (b) 50.547 kHz (c) 64.334 kHz

Fig.4 Stress distribution of T-shaped specimen when operating in important vibration modes.