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Estimation for Bolt Fastening Conditions of Thin Aluminum Structure Using PZT Sensors

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Abstract

This work presents a study on PZT impedance-based method, it is one of the NDT(Non - Destructive Technique). We study about assessment of the square-structure health condition by impedance-based technique using PZT patches, associated with longitudinal wave propagation. Health conditions of the square-structure controlled by bolt fastening condition is adjusted by torque wrench. In order to estimate the damage condition numerically, we suggest the evaluation method of impedance peak frequency shift.

Keywords: PZT sensor; Impedance based health mouitoring

1. Introduction

In modern society, operation of infra-structures such as bridges, tunnels, electricity transmission towers, large vessels and other large buildings is very important and its function must always go on.

Stars Grand Bridge collapsed in 1994, and the next year, Sam-pung Department Store collapsed in Korea. In San Francisco, the Oakland Bridge also collapsed due to structural malfunction. Similar disasters have occurred in Japan, including the collapse of an electricity transmission tower. In China, the South Gate Bridge collapsed in 2002. Similar such accidents have occurred in many countries. These mishaps caused enormous damage of human life and properties, and also illustrated the importance of developing safety techniques for large structures as well it is suitable for other important facilities, such as aircrafts, high speed railways, fuel containers, and electrical facilities. In general, the above structures run under heavy and alternate load and formidable natural conditions, so the damages occur with much higher probability.

Moreover, in Korea, Important infra-structural facilities were constructed between the 1970's and 1980's. This structure's Life is almost ended. The prevention of structural damage of large facilities is an important issue, and numerous countermeasures have been developed to prevent and monitor the deterioration of infra-structural facilities.

Studies about health monitoring technology of structures, which can easily estimate the extent of damage accumulated in the structure, and studies on quantitative non-destructive testing and health monitoring of large-scale structure have received considerable attention and proceeded in many developed countries, including the United States of America, Japan and etc.

2. Impedance measurement law

2.1 Impedance measurement by using PZT

Plates that have bolt connections possess an

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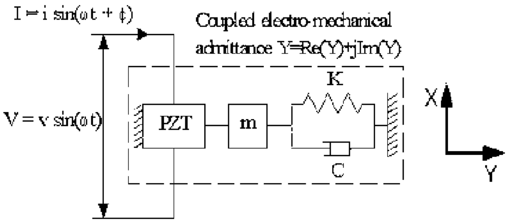

Fig. 1. Degree of freedom model of a structure attached with piezoelectric sensors.

important role in all types of structures. Damage detection that is based on plates that have bolt connections is universally significant. We present the simulation of several real-time damages, i.e. the location of the bolt loosening and the extent of the bolt loosening. The experimental setup is comprised of an impedance analyzer HP4192A, PZT sensors and a notebook computer with software, GPIB interface cables and a plate specimen. A 0.3mm thickness is selected for the experimental investigations to efficiently generate the longitudinal elastic wave for the rectangular PZT sensors of 25mm length and 4mm width. In general, one PZT sensor that is bonded on the surface of the structure dominantly generates the traverse or bending wave; however, the longitudinal wave is required for the damage detection along with the plates in the experiments.

$$Y = i\omega \frac{w_a l_a}{h_a}\left[\varepsilon_{33}^{Y}(1-i\delta) - \frac{Z_i(\omega)}{Z_i(\omega)+Z_a(\omega)} d_{3x}^{2} Y_{xx}\right] \quad (1)$$

If the impedance of an undamaged structure is constant, then we can assume that the band of resonance frequency may be shifted by the variation of impedance due to damage. Therefore, our goal is to establish the monitoring technique which can evaluate the damage of structure by the types and extent of damage.

2.2 Measuring object

Triangular and square structures are mainly discussed. In this paper, the experiment is adjusted to estimate the assembly damage of the square structure.

Through the experiment, the transverse direction of Parts A and B is tested to obtain the impedance. Whether the shift of Parts C and D can be detected or on depends on the bolt joint torque.

A total of 16 bolts is applied with a load of 3 N·m by torque wrench in Part A, B, C and D. By using the

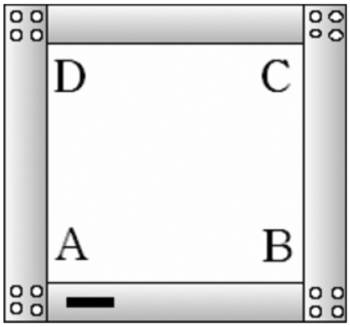

Fig. 2. Square Structure which uses 4 aluminum beams.

Table 1. Properties of aluminum beams.

Aluminum Beam element	**Length**	**700**
	Width w_s	**20**
	Thickness	**2**
	Density	**2.70**
	Young's Modulus	**7.06**
Piezo-electric Element (C-6)	**Length**	**25**
	Width w_s	**4**
	Thickness	**0.3**
	Density	**7.4**
	Relative dielectric constant ε_{33}^{T}	**2000± 300**
	Piezo-electricity constant	**-195**
	Young's Modulus	**5.8**
	Induced loss	**2.1**
	Frequency constant	**1400**

torque wrench, it is easy to apply moment of different values to each bolt. In addition, a total of 12 bolts of Parts B, C and D are tightened by 3N·m, but accordingly, the torque of bolts in PartA changes gradually from 0.5N·m to 0N·m, and the impedance is been measured simultaneously.

3. Experiment

In this experiment, the aluminum structure is suspended with both ends on the support of a sponge foundation, on which can prevent the influence of distance can be avoided as possible. Two piezo-electric elements are arranged on the ends of the beam symmetrically to generate vertical elastic waves.

By using an impedance analyzer (HP 4192A) with PZT, we can find whether there is minute damage in the structure and what the form and magnitude of the damage is. To measure the mechanical impedance of the aluminum beams, a frequency range and resolution are input into the impedance analyzer by using a computer. A definitive alternating signal corresponding to the input data is transmitted to the PZT, the electric potential within the PZT changes due to the harmonic longitudinal elastic wave generated in the beam, and the change of the electric impedance processed by an impedance analyzer is transmitted to the computer.

4. Impedance response of a normal structure

When both ends of the beam are free or fixed, the natural frequency of a beam by a longitudinal elastic vibration is given by:

$$f_n = \frac{c}{2l} n = \frac{n}{2l}\sqrt{\frac{E}{\rho}} \qquad n = 1,2,3,4,...... \qquad (2)$$

Where C is phase velocity of the beam, l is length of the beam, E is the elastic coefficient, and ρ is the density. Substituting the data of Table1 into Eq. (2), the natural frequency f_n of the beam is 3.531*KHz*.

Figure 3 presents the measurement results of the impedance response from 1 *KHz* to 150 *KHz* in a normal aluminum beam. The impedance response consists of a real and an imaginary part. We used the real part of the impedance to identify the resonant frequency of beam with respect to the structural response, and the real part also has a high measurement accuracy. The frequency range of the peak shown in Fig. 3 is 3.531 *KHz*. This value is almost the same as the value of 3.456 *KHz* calculated in Eq. (2).

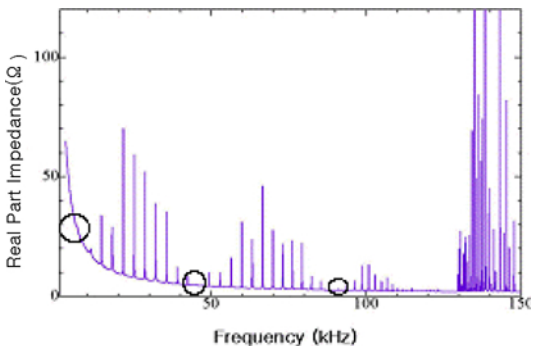

Fig. 3. Aluminum beam's impedance waveform.

5. Minute damage measurement and analysis of structure

5.1 Measurement and testing of square-structure

The impedance wave of a square structure was measured. In this case, the shifting tendency of

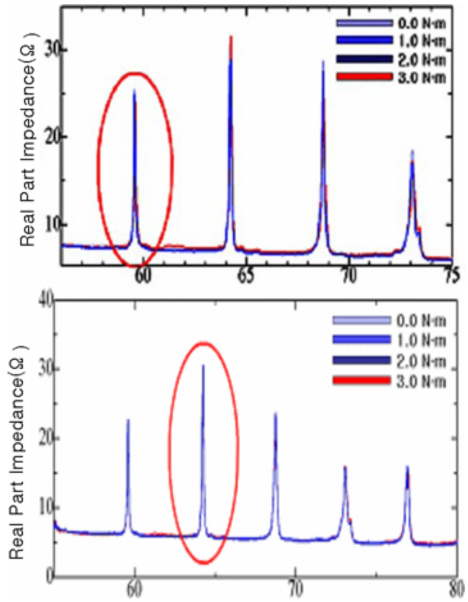

Fig. 4. Impedance response of Part A with 55KHz~75KHz and 55KHz~80KHz.

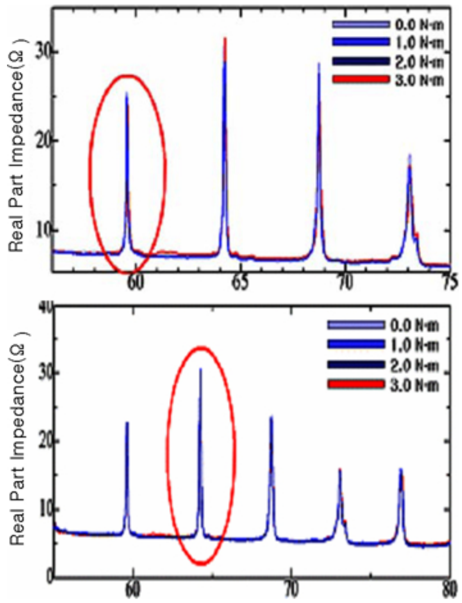

Fig. 5. Impedance response of Part A with 55KHz~75KHz and 55KHz~80KHz.

Table 2. Frequency peaks of parts A, B, C, D under health conditions.

Hole A(a3bb3c3d3)-B(a3b3c3d3)-C(a3b3c3d3)D(a3b3c3d3)					
Frequency(kHz)	59.5695	64.1910	68.7540	73.0830	76.9440
Peak( )	2.25e+01	2.46e+01	2.75e+01	1.73e+0	1.72e+01

Table 3. Quantitative frequency peak of bolt joint of parts A, B, C, D.

Hole A(a0b3c3d3)-B(a3b3c3d3) -C(a3b3c3d3)-D(a3b3c3d3)	Frequency (kHz)	59.04	63.44	67.72	72.44	76.88
	Peak(Ω)	2.91e+02	3.51e+01	1.21e+01	1.09e+01	9.39e+00
Hole A(a1b3c3d3)-B(a3b3c3d3) -C(a3b3c3d3)-D(a3b3c3d3)	Frequency	59.04	64.00	68.64	72.76	76.84
	Peak	1.08e+01	2.39e+01	2.07e+01	2.05e+01	1.49e+01
Hole A(a2b3c3d3)-B(a3b3c3d3) -C(a3b3c3d3)-D(a3b3c3d3)	Frequency	59.48	64.16	68.68	72.92	76.80
	Peak	2.78e+01	3.48e+01	2.20e+01	2.41e+01	1.73e+01
Hole A(a3b3c3d3)-B(a0b3c3d3) -C(a3b3c3d3)-D(a3b3c3d3)	Frequency	58.84	63.32	67.80	72.28	76.80
	Peak	2.06e+01	2.73e+01	1.48e+01	1.45e+01	1.13e+01
Hole A(a3b3c3d3)-B(a1b3c3d3) -C(a3b3c3d3)-D(a3b3c3d3)	Frequency	59.36	64.12	68.64	72.88	76.80
	Peak	2.38e+02	2.05e+01	2.30e+01	2.02e+01	1.23e+01
Hole A(a3b3c3d3)-B(a2b3c3d3) -C(a3b3c3d3)-D(a3b3c3d3)	Frequency	59.48	64.16	68.72	72.96	76.80
	Peak	2.49e+01	2.89e+01	2.40e+01	2.19e+01	1.70e+01
Hole A(a3b3c3d3)-B(a3b3c3d3) -C(a0b3c3d3)-D(a3b3c3d3)	Frequency	59.56	64.02	68.72	73.08	76.96
	Peak	2.55e+01	3.06e+01	2.89e+01	1.86e+01	1.78e+01
Hole A(a3b3c3d3)-B(a3b3c3d3) -C(a1b3c3d3)-D(a3b3c3d3)	Frequency	59.56	64.20	68.72	73.08	76.92
	Peak	2.62e+01	2.97e+01	2.44e+01	1.81e+01	1.77e+01
Hole A(a3b3c3d3)-B(a3b3c3d3) -C(a2b3c3d3)-D(a3b3c3d3)	Frequency	59.56	64.24	68.72	73.04	76.96
	Peak	2.55e+01	2.94e+01	2.82e+01	1.76e+01	1.84e+01
Hole A(a3b3c3d3)-B(a3b3c3d3) -C(a3b3c3d3)-D(a0b3c3d3)	Frequency	59.56	64.24	68.76	73.08	76.96
	Peak	2.22e+01	3.02e+01	2.40e+01	1.58e+01	1.51e+01
Hole A(a3b3c3d3)-B(a3b3c3d3) -C(a3b3c3d3)-D(a1b3c3d3)	Frequency	59.60	64.24	68.76	73.04	76.92
	Peak	2.21e+01	3.07e+01	2.31e+01	1.59e+01	1.61e+01
Hole A(a3b3c3d3)-B(a3b3c3d3) -C(a3b3c3d3)-D(a2b3c3d3)	Frequency	59.60	64.24	68.72	73.08	76.96
	Peak	2.49e+01	3.24e+01	2.56e+01	1.76e+01	1.78e+01

frequency wave of parts A and B is shown in Table 2. The frequency wave for parts C and D, was quantitatively measured, but it was unreliable because the frequency amplitude was too small. Therefore, an additional piezoelectric sensor is attached to the symmetric position relative to the damage end of the beam. Table 2 shows the frequency peak of part A, B, C, and D under health conditions, and each bolt is tightly fastened without looseness.

6. Conclusions

Tightly fastened bolt results are proposed to estimate the damage of a structure.

The conclusions of this study are as follows;

Based on the longitudinal elasticity principle, impedance method is feasible and can be used to obtain the impedance resonance frequency with much larger frequency band.

Several experiments confirmed the feasibility of the impedance method.

Resolving power has small effect on the detecting accuracy of impedance resonance frequency and it make no difference when the impedance resonance frequency is between 0.5Hz and 10Hz

Peak frequency shift amount is proposed for the graphics of damage estimation.

The study proposed in this paper is consistent with the case of minute damage.

For example, whether or not the change of material property can be influenced by rust or corrosion, and internal stress influenced by metal fatigue.

First, since the mechanical impedance will change with the change of stress, the change of internal stress by metal fatigue can be detected through the change of electrical impedance of the piezoelectric sensor.

As well, the elastic modulus and density are changed when the material property is changed by rust or corrosion. Tests showed that the electrical impedance changes because the stationary wave changes inside materials. The method based on the concept that the physical characteristics of a structure, because the change of electrical impedance of piezoelectric element is sensitive, and thus, can be used to forecast the changing state of damage. But it is difficult confirm the position of damage. An alternative method is to attach many more piezoelectric elements to find the position of damage when driving method permitted.

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