MODEL-BASED HEALTH MONITORING OF USING A PIEZOCERAMIC ACTUATOR-SENSOR TO QUANTIFY AND LOCALIZE DAMAGE OF BOLTED JOINT STRUCTURES

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1. Introduction

This paper presents a structural health monitoring of using a piezoceramic (PZT) actuator-sensor in conjunction with numerical model-based methodology to quantify and localize damage of bolted joint structures. Basic principle of this health monitoring is to utilize high-frequency excitation through surface-bonded PZT actuator-sensor to detect changes in structural properties due to damage. An experiment is performed to detect damage of a two-joint aluminum beam structure. Due to high-frequency range employed, a numerical model of the structure is formulated by using spectral element method (SEM)[1] in order to quantify and localize the damage.

2. The principles of structural health monitoring using a PZT actuator-sensor

A PZT patch can be used as an actuator-sensor by utilizing its electro-mechanical coupling property. This property is that it generates electric charge when mechanical force is applied and conversely it mechanically deforms in the presence of an electric field. First, a PZT patch is bonded on a structure, then, it is driven by a fixed alternating electric field in order to excite the structure. When the structure is vibrated, the PZT patch also vibrates and then generates an electric current. The electrical impedance, which is the ratio of the applied voltage and the resulting current, is measured by an impedance analyzer. The electrical impedance is directly influenced by structural properties. Therefore, by observation of the electrical impedance, the information of damage of the structure can be obtained.

3. Experimental set-up

An experimental set-up is shown in Fig. 1. A bolted joint aluminum structure was hung from the ceiling. The whole length of the structure was 1 m. The cross-sectional area of the aluminum bars was 30 mm x 1 mm. Bolted joints were at 0.25 m and 0.75 cm from the top end. Total length of the bolted joint part was 80 mm. Four 3-mm-steel bolts with washers and nuts were used. A 30 mm x 35 mm PZT patch was bonded at a distance of 2.5 cm from the joint A by using cyanoacrylate adhesive. The PZT patch was wired to the impedance analyzer. Damage was simulated by loosening the bolts. Both joints were arbitrarily loosened from 20 cN-m to 15, 10, 8, 6, 4, 2 and 0 cN-m as shown in table 1. Then, a constant voltage of 10 V with varied frequency was used to excite the structure and the electrical impedance was measured for each damage case. Eventually, the impedance was observed to investigate the damage of the structure.

4. Numerical models and damage identification

Numerical model to simulate the bolted joint structure is formulated by using the SEM. The model is assumed to be 1-dimensional. It consists of spectral beam, bonded-PZT beam and bolted joint elements. The detail of the formulation of these spectral elements and the calculation of the impedance can be found in literature[1]. At the bolted joint element, the connection of structural elements at the bearing surfaces is modeled by spring and dashpot to represent the stiffness due to contact pressure and dissipation of energy. The spring stiffness K and damping η are functions of bolt torque. The method to identify the value of K and η can be found in literature[1] and their values are shown in Fig. 2. To identify the damage, the value of K and η are used to calculate the impedance for all possible cases of damage. Then, the measured impedance is compared with the calculated impedance. The damage case that gives the best match of the measured impedance will be the result of the damage identification.

Keywords: Structural health monitoring, piezoceramic, bolted joint, electrical impedance, spectral element method
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5. Results and discussions

The electrical impedance measured for different values of bolted torque is shown in Fig. 3. The peaks shown in the figure represent the resonance of the impedance. It can be seen that when the bolts are loosened, there is a change in the impedance, indicating a change in structural properties. By using the numerical model and the damage identification method, the severity and location of the damage can be identified as shown in table 1. It can be seen that when there is severe damage (torque ≤ 4 cN-m), the severity and location of the damage can be identified accurately. However, for moderate damage (torque ≥ 6 cN-m), some damage cases are identified incorrectly. This is because there is only small change in the spring stiffness and damping of the bolted joints when the torque is higher than 6 cN-m as shown in Fig. 2.

6. Conclusions

The model-based health monitoring of bolted joint structures using a PZT actuator-sensor was presented. An experiment was performed on a two-joint aluminum beam structure. The experimental results show the ability of this method to detect the damage. A numerical model of the structure was formulated by using the SEM. By using the numerical model, it is able to quantify and localize the damage of the bolted joint structure.

References

1. Ritdumrongkul S., Abe M., Fujino Y. and Miyashita T., 2004. ‘Quantitative health monitoring of bolted joints using a piezoceramic actuator-sensor’, *Smart Material and Structures*, Vol. 13, No. 1, 20-29.

Figures and tables

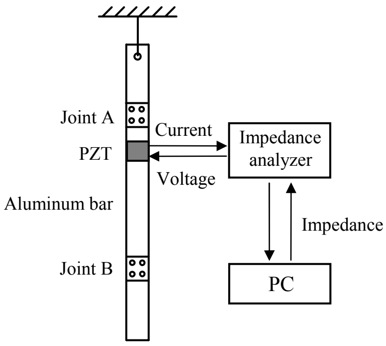

Fig. 1 Experimental set-up.

Table 1 Damage cases.

Cases	Actual torque (cN-m)		Identified torque (cN-m)	
	Joint A	Joint B	Joint A	Joint B
1	0	20	0	10
2	6	20	10	20
3	10	20	10	20
4	20	2	20	2
5	20	15	10	20
6	2	8	2	6
7	6	15	10	15
8	0	2	0	2
9	4	0	4	0
10	2	0	2	0

* Incorrectly identified values are shown in red color.

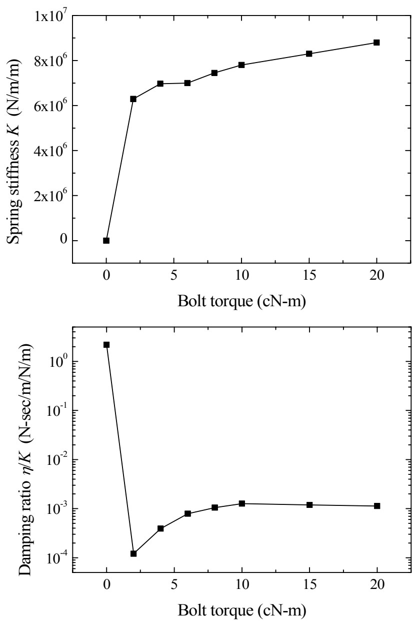

Fig. 2 (a) Spring stiffness (b) damping.

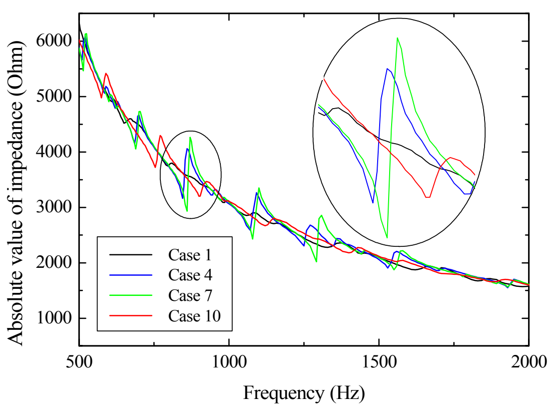

Fig. 3 Measured impedance.