# QUANTITATIVE HEALTH MONITORING OF BOLTED JOINTS USING PIEZOCERAMIC ACTUATOR-SENSOR

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## 1. Introduction

This paper presents the use of piezoceramic (PZT) actuator-sensor to quantitatively detect damage of bolted joints. Basic principle of this technique is to utilize high-frequency excitation through surface-bonded PZT actuator-sensor to detect changes in structural properties due to damage. To quantitatively monitor the damage, a numerical model of structure is formulated by using spectral element method (SEM)<sup>1</sup>. By utilizing this proposed model, the damage can be quantitatively identified as the change in stiffness and damping at the bolted joint. Thus, this technique has a potential to efficiently detect damage of bolted joint.

### 2. Principle of structural health monitoring using 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 is hanged from the ceiling. The whole length of the structure is 1 m. The aluminum bars have cross-sectional area of 30 mm x 1 mm. The joint is at 0.25 m from one end. Total length of the bolted joint part is 80 mm. Four 3-mm-steel bolts with washers and nuts are used. Damage is simulated by loosening of the bolts. In reality, structures are designed to resist external loading such as tensile force. The dynamics properties of bolted joint may be affected by the presence of tensile force. Hence, tensile force is applied to the structure by hanging weight as shown in Fig. 1.

A 30 mm x 35 mm PZT patch is bonded at a distance of 2.5 cm from the bolted joint by using cyanoacrylate adhesive. The PZT patch is wired to the impedance analyzer. A constant voltage of 10 V with varied frequency is used to excite the structure. The electrical impedance is measured, hence the electrical impedance for different values of bolted torque and tensile forces can be observed to investigate the change in structural properties.

## 4. Numerical models

Numerical model to simulate the bolted joint structure used in the experiment is formulated by using SEM. The model is assumed to be 1-dimensional. It consists of spectral beam elements, a bonded-PZT beam element and bolted joint elements. The detail of formulation of these spectral elements can be found in literature<sup>1, 2</sup>. At the bolted joint element, transverse spring stiffness and damping are taken as unknown parameters. These parameters are identified by parameter fitting method, Genetic algorithm<sup>3</sup>, to achieve a good agreement between the measured impedance and the calculated impedance from the model. Eventually, transverse spring stiffness and damping for different values of bolted torque will be obtained and the damage will be identified as change in these values of the transverse spring stiffness and damping.

Keywords:
 Quantitative 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. 2. The peaks shown in the figure represent the resonance of the impedance. It can be seen that when the bolts are loosened from 6 to 2 cN-m torque, the resonance peaks move to lower frequencies and height of the peak is reduced. For zero torque case, the peak height is small and position of the peaks is completely different from the other cases. By using the numerical model, the identified values of transverse spring stiffness and damping for different bolted torques and tensile forces are shown in Fig. 3. It can be seen that the spring stiffness reduces and in general the damping increases when the bolts are loosened. It also can be seen that tensile force affects dynamics properties of bolted joint.

#### 6. Conclusions

The quantitative structural health monitoring by using PZT actuator-sensor was presented. Experimental results show the ability of this method to detect the damage. By using the numerical model, the loosening of bolts can be quantitatively identified as the change in stiffness and damping at the bolted joint, indicating a high potential of this method in order to quantitatively monitor structural damage.

#### References

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Figures



Fig. 1 Experimental set-up



Fig. 3a Identified spring stiffness



Fig. 2 Measured electrical impedance



Fig. 3b Identified damping