SELF-MONITORING AND SELF-HEALING BOLTED JOINTS USING SHAPE MEMORY ALLOY

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ABSTRACT: This paper describes the smart structural system using smart materials for real-time monitoring and active control of bolted joints in steel structures. The goal of research is to reduce the likelihood of failure and the cost of maintenance of the structures. This concept combines impedance based health monitoring techniques with shape memory alloy (SMA) washer to restore the loosen bolt's tension. The impedance-based structural health monitoring (SHM) techniques has been used to detect loose bolts in the bolted joints. Through monitoring the measured electrical impedance and comparing it to a baseline measurement, the bolt loosening damage could be detected. Once loosening damage was detected in the bolted joint, the external heater which was bonded to SMA washer actuated the washer. Then the heated SMA washer expanded axially and adjusted bolt tension to restore lost torque. Experimental study was conducted by integrating piezoelectric material based structural health monitoring and SMA-based active control functions on a bolted joint, and the performance of a smart self monitoring and self-healing bolted joint system was demonstrated.

***Keywords**: Bolted Joints, Electro-mechanical Impedance, Piezoelectric Material, Self-healing, Shape Memory Alloy, Structural Health Monitoring*

1. INTRODUCTION

The bolted joints are prevalent in various structures. These connections invariably promote damage growth and are often difficult to inspect due to the nature of geometry and/or the loading in structures. The concept of this system is monitoring and detecting the self-loosening damage and controlling it actively. This concept combines the impedance-based health-monitoring technique with actuators to restore tension in a loose bolt. The actuators are included in the joint as shape memory alloy (SMA) washers. SMA has the ability to convert heat into mechanical energy through a phase transition. The theory behind these techniques and the overview of proposed system are presented in the following sections.

2. IMPEDANCE-BASED STRUCTURAL HEALTH MONITORING

The basic concept of the impedance method of structural health monitoring is to use high frequency vibrations to monitor the local area of a structure for changes in structural impedance that would indicate damage. The impedance measurements can easily give information on changing parameters, such as resonant frequencies, that will allow the detection of damage. Since the piezoelectric patch is bonded to the structure, the structure is deformed along with it and produces a local dynamic response to the vibration. The response of the system is transferred back from the piezoelectric patch as an electrical response. The electrical response is then analyzed and, since the presence of damage causes the response of the system to change, damage is shown as a phase shift or magnitude change in the impedance. If the bolted joint get loosened the magnitudes of the resonance peak decreases which suggests an increasing in damping, and the peaks shift leftwards, indicating a reduction of joint stiffness. And the damage was evaluated quantitatively using the damage metrics RMSD (Root Mean Square Deviation) in conductance signature with respect to those healthy states.

3. SELF-HEALING BOLTED JOINTS USING SHAPE MEMORY ALLOY

As mentioned earlier, the damage control portion of the self-healing bolted joint utilizes SMA technology. The shape memory effect is the ability of certain alloys to have their shape changed at low temperatures and stay in their new form until they are heated. The basic principle of this technique is that the temporary adjustment of the decreased torque can be achieved using a shape memory alloy actuator around the axis of the bolt shaft. To heat the SMA washer an external heater is bonded to SMA washer and the SMA washer is inserted between the bolt and the nut. When the bolted joint is loosened the PZT sensor detects the damage and then the heater heats the SMA washer. The heated SMA washer expands axially

4. EXPERIMENTAL RESULT

The test specimen was constructed using two 3x200x400mm beams bolted together with 3x200x200mm steel plates. A PZT sensor with size of 20x20mm is attached to the bar. The joint was initially tightened to 40Nm representing its undamaged intact state and the impedance was measured. The joint was then loosened to 15Nm and measured again. After the measurement of the 'loose' case, power was supplied to the external heater bonded to the SMA washer. The SMA washer expanded axially to restore lost torque in the joint as shown in Fig. 1.

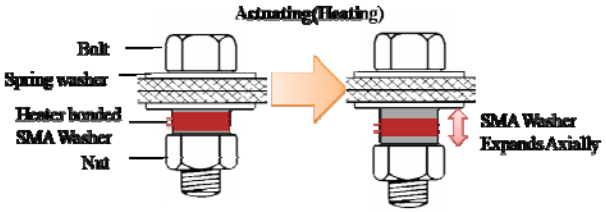

Fig. 1 Smart Self-healing Bolted Joint

A final impedance measurement was then taken. As shown in Fig. 2, the response of the beam after actuation returns to the original frequency position of the tight joint. From impedance data, RMSD value was calculated to evaluate the damage quantitatively. As shown in Fig. 3 as the bolted joint was loosened, the difference between with the baseline got bigger and after actuating the SMA the difference got smaller, which means the bolted joint restored the lost torque.

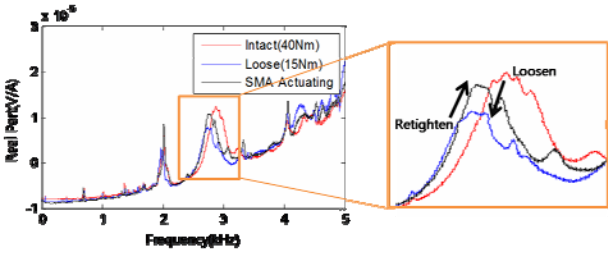

Fig. 2 Impedance measurements from 0~5 kHz

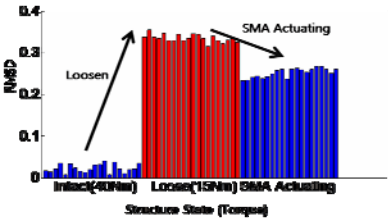

Fig. 3 RMSD indices obtained impedance data

5. CONCLUSION

Smart self-healing bolted joint system is a smart system to repair in a self-healing manner bolt-loosening defects using SMA washers.

1. Experimental study has shown that impedance is viable measure of torque change to monitor the bolt loose damage.
2. SMA washer with an external heater is effective to restore the lost torque of the bolted joint.

Extensive efforts are currently devoted to studying several implementation issues to handle real-life field applications associated with bolted joint structures automatically.

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