STRUCTURAL HEALTH MONITORING USING METAL WIRE BASED PIEZO-IMPEDANCE TRANSDUCER

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Abstract

Electromechanical impedance (EMI) method is a new non-destructive evaluation technique which is very effectively employed now a day in the field of structural health monitoring. In this study PZT patches are used to determine response of undamaged and damaged structure. One of the major drawback for the EMI method is the brittleness of the PZT material, thus making it difficult to attach on the curved, complex geometry and the surfaces under continuous impact from external load. This study presents a technique to overcome the difficulty of application of PZT on curved surface by introducing steel wire between structure and PZT element. It will eliminate direct bonding of PZT element to such complex structure. The method has shown promising results for damage detection of steel beam. This paper demonstrates the metal wire based EMI technique for damage assessment of beam.

***Keywords**: EMI Technique, Flaw Detection, PZT Sensor, Structural Health Monitoring*

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1. INTRODUCTION

1.1 General

Civil Engineering infrastructure development represents the spine of growth for any developed country. In present non-destructive evaluation EMI technique of Structural Health Monitoring the state of any structure at any stage of life is monitored using a smart material (Piezoelectric patches) which acts as a sensor as well as actuator. After applying mechanical stress the PZT produces electrical charge and vice versa. Due to its light weight and its availability in various shapes and sizes, has been used widely for structural dynamics applications. The only limitation of this technique is the brittleness of PZT patches and its direct bonding to curved surfaces, complex surfaces. Such surfaces does not provide flat portion for effective bonding of PZT patch with parent surface. To overcome such problem the technique is introduced in which direct bonding of PZT patch on host structure is eliminated by introducing a metal wire between structure and PZT element by means of adhesive.

The major advantage of using a steel wire with EMI method is the elimination of the need for attaching the brittle PZT element onto the surface of the host structure. Since the PZT is attached as a part of the steel wire path, resonance at certain frequencies are virtually maintained regardless of the target Structure (Na and Lee 2012b). In addition to this it is also possible to monitor a structure with elevated temperature. As steel has a melting point over 1000˚C PZT is suitable for structures such as pipelines of boiler tubes or other facilities experiencing high temperature also.

The impedance based method have been effectively functional on a number of steel structures. Park *et al.* (2000) reported significant proof of concept applications of EMI technique on civil structural components such as composites reinforced masonry walls, steel bridge joints and pipe joints. They also extended the EMI technique to complex structure, such as steam pipes and boilers in power plants. Du *et al.* (2013) presented a feasibility study on the crack detection and severity monitoring of pipelines using PZT transducers. Na and Lee (2012 a) reported a method for selecting Resonance frequency range utilized for damage detection of composite structures. Further they worked on Steel wire electromechanical impedance method using a piezoelectric material for composite structures with complex surfaces. Bhalla and Naskar (2014) recently reported experimental study on Metal wire based variant of EMI technique for steel structures. The main objective of the present paper is to detect flaw and investigate extent of damage of steel beam.

In the present study, an experimental setup is developed to extract the structural response from the piezoelectric transducer (PZT) patches bonded through the steel wire and to predict the damages by using high frequency technique. The structural damage is identified by studying the responses for healthy state and damaged state and comparing them using EMI technique. The results of the experimental studies showed the powerful applicability of the damage detection using high frequency technique of PZT patches for steel structure.

2. ELECTRO MECHANICAL IMPEDANCE TECHNIQUE

Electro-Mechanical Impedance (EMI) technique is High Frequency Technique. This technique has been widely established as an SHM/NDE technique. This technique makes use of piezoelectric patch as admittance transducer by utilizing their direct and converse piezoelectric properties simultaneously (Bhalla 2004). Physical changes such as mass, stiffness or damping causes a change in the mechanical admittance of the structure and all other PZT properties remain constant. Due to electromechanical coupling of the piezo transducer this change in the mechanical admittance causes a change in the electrical admittance of the piezo electric material. Hence by monitoring the change in electrical admittance signature with respect to baseline measurement damage occurred in a structure can be identified. The signatures are acquired using LCR meter. The LCR meter imposes a voltage signal to the PZT patch over some frequency range and acquire signature for intact and damaged case.

3. EXPERIMENTAL INVESTIGATION

1.2 General

To estimate the efficiency of improved Electro-Mechanical Impedance technique in flaw detection in steel structures, experiments are performed on steel beam using piezoelectric materials in conjunction with metal wire. The PZT utilizes its dual property i.e act as actuator and sensor simultaneously. Signature of the structure in healthy state i.e base line signature and damage states is obtained and analyzed.

3.2 Materials and Specimens

In this experimental study, a steel beam, 300mm X 24mm X 1mm, were instrumented with PZT patch for two different support conditions.

a) Simply Supported
b) Fully supported
c)

The piezo-electric material used is PZT patch of high frequency range. The PZT patch is PZT-5H grade of size 10mmX10mmX 0.2 mm which is manufactured at the Central Electronics Limited, Sahibabad (Shown in Fig.1(a)). The wire used for is coaxial head wire so that losses of signatures are minimized. Araldite is used as adhesive for bonding of piezoelectric material with the steel wire and same wire attached to structure with adhesive. For ensuring proper bond layer the adhesive was cured for 24 hrs. Impedance Analyzer (LCR meter E4980A) (shown in Fig. 1(b)) of frequency range of 20 Hz to 2MHz was used for obtaining and analyzing the responses of PZT patches for damage stage of host structure.

Figure 1(a): PZT 5-H grade sample

Figure 1(b): LCR meter

USB cable is used for transferring the data from LCR meter to a personal computer and the VEE Pro program developed for the measurement of Conductance and Susceptance for a user specified frequency range.

3.3 Experimental Set-up

The test was performed to analyze the effectiveness of PZT patches for flaw detection in steel structure. Initially, the PZT patch was soldered out through two electrodes with the help of co-axial cable, and then it was bonded to the one of the end of steel wire and other end of steel wire is attached to the beam with the help of high strength epoxy adhesive Araldite. The wires soldered out to PZT patch were connected to LCR meter through Connecting Fixture. The frequency range was set between 100 kHz to 250 kHz in impedance analyzer, which excites the PZT patch. The PZT patch transfers these vibrations to the structures through steel wire and reflected back. The response extracted i.e. Conductance (G) and Susceptance (B) is measured through LCR meter. This data is transferred to personal computer (PC) by USB cable and Conductance Vs Frequency and Susceptance Vs Frequency are directly plotted in VEE Pro 9.31 software. The experimental setup is shown in Fig.2 (a) and (b) and the connection between PZT and structure with steel wire shown in Fig.3 (a) and (b).

Fig. 2 (a): test setup of S S Beam

Fig.2 (b): test setup of Fully Supported Beam

Fig. 3 (a): Bonding of PZT patch and wire

Fig. 3 (b): Bonding of metal wire and beam

These extracted responses are also known as Signatures i.e. Conductance Signature and Susceptance Signature for that state. This data can be saved in excel format and can be available as and when required. This test was performed in two stages i.e. in the first stage signatures for healthy condition of the structure and in second stage for damaged conditions of beam. Signature of the structure in healthy state is called the base line signature and the signature after a time lapse, which is called secondary state conductance signature. The data for both the stages is recorded and compared.
The tests were conducted on steel beams for two different support conditions viz. Simply supported and Fully supported condition.

The artificial cut of 2mm wide 8mm deep was made through the thickness of beam 140 mm from metal wire. As shown in fig. 4.

Fig. 4: Enlarged view of Damage

Since the artificial damages were created in steel beam, the conductance and the suceptance were measured at each stage for each support condition. Presence of damage in the steel beam was detected using the EMI technique. The admittance signatures (consisting of the conductance and the suceptance) of the PZT patch were obtained in the frequency range 100-250 kHz for the undamaged/damaged and for both support conditions. The responses obtained are compared and results are discussed in next section.

4. RESULTS AND DISCUSSION

Using EMI technique, tests were conducted on steel beam for two support conditions. The signature of the PZT patch is acquired over a high frequency range (100-250 kHz), by means of LCR meter for undamaged and damage stages.
The formulated results from the test have been graphically plotted. Fig.5(a) and Fig.5(b) shows the plot between the conductance (G) Vs frequency and Susceptance (B) Vs frequency respectively and are obtained from PZT for frequency range 100 kHz to 250 kHz for the undamaged stage and for simply supported steel beam.

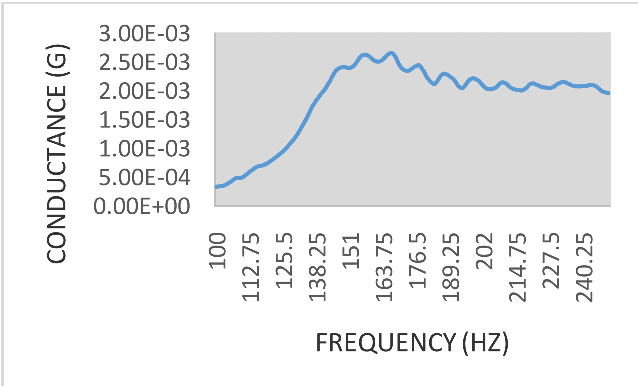

Fig. 5 (a): PZT Conductance Signature for SS steel beam

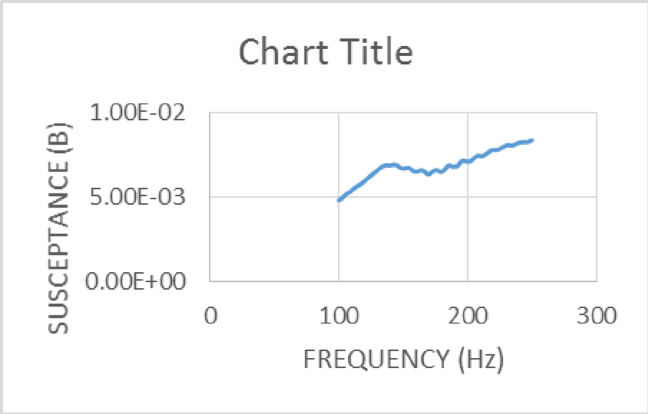

Fig. 5 (b): PZT Susceptance Signature for SS steel beam

Fig.6 (a) and Fig.6 (b) shows the plot between the conductance (G) Vs frequency and Suspectance (B) Vs frequency and are obtained from PZT bonded through the metal wire at frequency range 100 kHz to 250 kHz for the undamaged stage and damaged stage for simply supported beam.

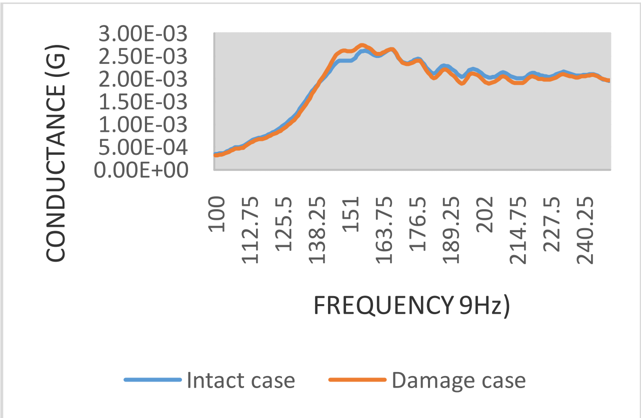

Fig. 6 (a): Conductance for damaged and intact case S. S. beam

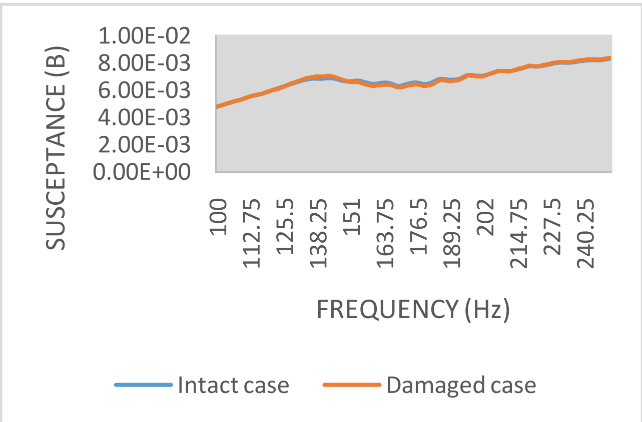

Fig. 6 (b): Susceptance for damaged and intact case S. S. beam

It is obvious that the changes in conductance after damage are more prominent as compared to suspectance signature. Fig.7 (a) and Fig.7 (b) shows the plot between the conductance (G) Vs frequency and suspectance (B) Vs frequency respectively and are obtained from PZT bonded through steel wire for fully supported condition at frequency range 100 kHz to 250 kHz for the undamaged and damaged stage.

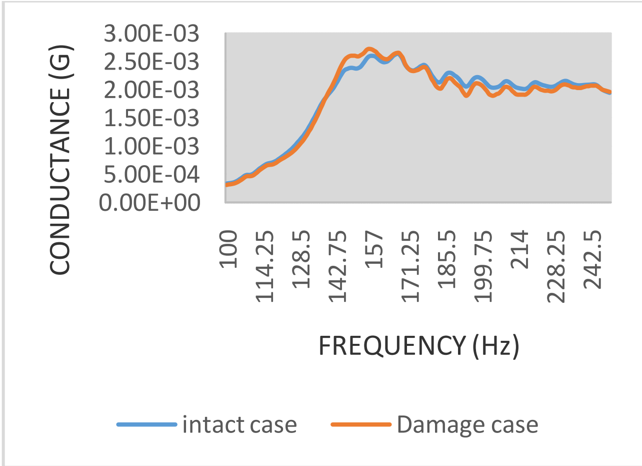

Fig. 7(a): Conductance for damaged and intact fully supported steel beam

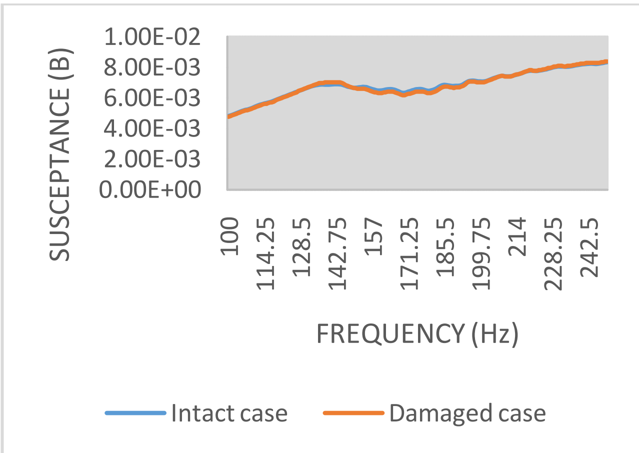

Fig. 7(b): Susceptance signature for damaged and intact case for fully supported steel beam

5. CONCLUSIONS

The beam specimen with different support conditions using wire based PZT patch were tested. The responses for two conditions i.e. without damage and with damage are compared and it is concluded that

- By comparing the results obtained for both the stages, it can be said that the responses for beam is different for healthy and damaged conditions. Changes in the responses in the form of horizontal and vertical shift of peaks are the indications of damage. Hence, structural health monitoring with Metal wire based variant EMI technique is effective tool for damage detection.
- As there is elimination of direct bonding of brittle PZT patch on the host structure the technique proved to be effective for curved and complex surface.
- The shifts in horizontal and vertical peaks are more prominent in conductance signatures.

6. REFERENCES

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