EXPERIMENTAL INVESTIGATIONS OF METAL WIRE BASED EMI TECHNIQUE FOR STEEL STRUCTURES

S. Naskar[a], S. Bhalla[a]
[a] Indian Institute of Technology Delhi, Delhi 110016
Email:susmita630000@gmail.com, sbhalla@civil.iitd.ac.in

Abstract:. Infrastructure construction is the second largest economic activity in India after agriculture and it is growing rapidly. Structural Health Monitoring (SHM) aims to provide new solutions for easy and swift inspection of engineered structures. Electromechanical impedance (EMI) technique is a relatively new useful and convenient technique in the area of SHM. Though this technique shows promising results in the area of SHM, the main disadvantage of this technique is the brittleness of the piezo-electric (PZT) material. To overcome this problem, a new variant has recently emerged wherein a metal wire is coupled with the PZT patch and then attached with the host structure. This paper primarily focuses on evaluating the metal wire based EMI technique for damage assessment of 2D structure. Test results show that the technique can effectively identify and locate damage on a 2D structure.

Keywords: Structural Health Monitoring (SHM), Piezo-electric material (PZT), Electromechanical impedance (EMI) Technique, Metal wire based EMI Technique

1. INTRODUCTION

Civil Engineering infrastructure development represents the spine of growth for any developed country. SHM offers precise information that can help the engineers to identify the state of the structures and if needed can target the specific regions to inspect. In the process of increasing the life span of any existing engineered structure, the concept of long term monitoring is evolving as a result of the new sensor technologies EMI is a relatively new non-destructive evaluation (NDE) technique, which uses a single PZT patch to act as an actuator and a sensor simultaneously [1]. On giving a mechanical stress, the PZT material produces electrical charge and vice versa. Due to its light weight and easily availability, PZT materials are used widely used for structural monitoring through EMI technique. But the main limitation of the technique is the brittleness of the PZT patch material and for this reason it is difficult to attach the patch on surfaces with the complex geometries. In addition, certain unfavorable situations prohibit direct bonding of PZT patches on the structure. To overcome the aforementioned problems, a metal wire attached in between the structure and the PZT patch has been demonstrated to be effective [2,3]. The main advantage of using a metal wire is the elimination of the need for attaching the brittle PZT element onto the surface of the structure. In this study the metal wire EMI technique is used to health monitor the steel plate having dimensions 1200X970 mm^2, subjected to progressive damage. The promising results of the experiments indicate the effectiveness of the proposed metal wire technique on steel structures.

2. ELECTROMECHANICAL IMPEDANCE TECHNIQUE

The EMI technique employs a PZT patch surface bonded to the monitored structure, to produce ultrasonic vibrations (in 30-400 kHz range) so as to derive a characteristic electrical signature of the engineered structure, which will contain vital information concerning the phenomenological nature of the 2D structure[4]. Electromechanical admittance can be decomposed and analysed to extract the impedance parameters of the structure. In this process, the PZT patch will act as an impedance transducer, which enables the structural identification for SHM. The PZT patch acts as actuator as well as sensor. The main idea of EMI technique is that the presence of damage in the host structure will affect the mechanical impedance and then the admittance of the PZT patch, will directly measured by an LCR meter which is shown in the Figure 1.

Figure1 Electrical impedance analyzer (LCR meter Agilent E4980)

The LCR meter imposes an alternate voltage signal to the bonded with PZT patch over the specified frequency and the changes in the admittance signaturegives the indication of strctural damage which can be easily accessed for the identification of damage assessment. This admittance signature is a function of stiffness, mass and damping behaviour of the assessed structure.

The schematic set up of the experimental set up is shown in the Figure 1 where the Agilent E4980A 20Hz-2MHz precision LCR meter is connected to a laptop and a specimen through USB cable. The values of conductance (G) and susceptance (B) were obtained by connecting in frequency range 100 to 150 kHz through the Agilent VEE Pro 9.0[5].

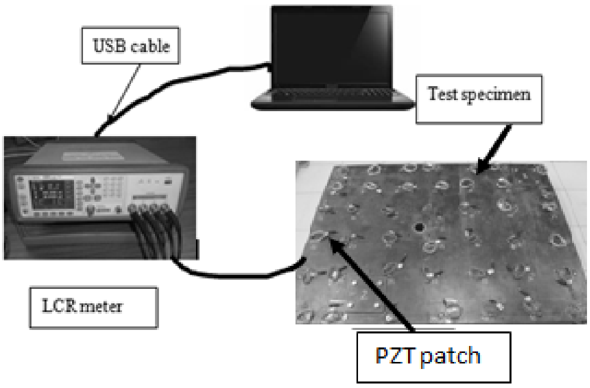

Figure2 General Schematic set up of the total system

In order to quantify the changes in signature due to damage, the index used is root mean square deviation i.e. RMSD.

RMSD was defined as [6],

$$\text{RMSD}(\%) = \sqrt{\frac{\sum_{i=1}^{i=n}(w_i - u_i)^2}{\sum_{i=1}^{i=n} u_i^2}} \times 100 \qquad (1)$$

Where, u_i (i= 1,2,3,……..,N) is the baseline signature

w_i is the signature obtained after damage.

3. SPECIMEN PREPARATION

The steel plate shown in Figure3 has dimension of 1270X970 mm^2 and is 8 mm in thickness. The chemical composition of the steel plate includes carbon of 0.23 %, manganese of 1.5 %, sulphur 0.045%, phosphorus of 0.045% and silicon of 0.40% as per IS-2062, 2006. The steel plate was supported on box section pipe of cross section 38X38 mm^2 and 3 mm thickness and the pipe was welded along the perimeter of the steel plate.

After the fabrication of the steel plate, metal wires of length 50.8 has been attached with the plate at two sides of it, and then PZT patches were attached on the plate and the metal wire with two part Araldite epoxy adhesive. The whole Plate with metal wire is shown in Figure 4.

The key feature of the proposed arrangement is that it drastically reduces the total number of sensors employed for SHM

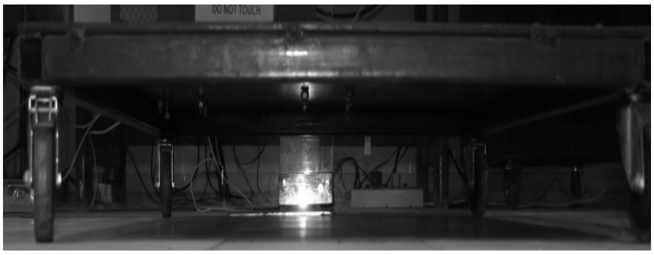

Figure 3(a) Side view of the Steel Plate of 1270X970 mm^2

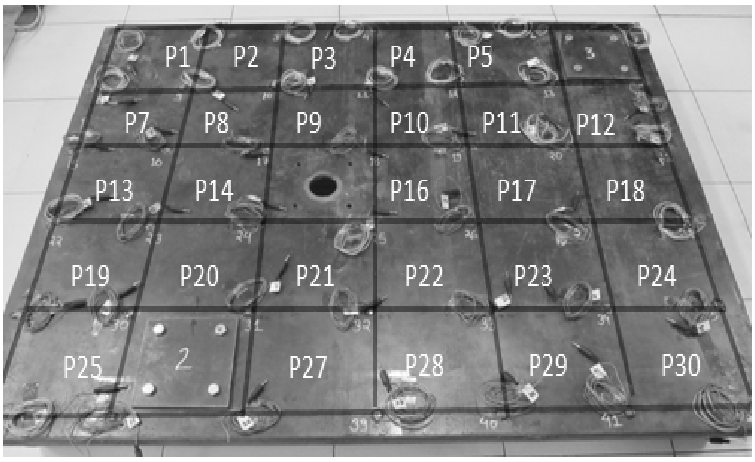

Figure 3(b) Front view of the Steel Plate of 1270X970 mm^2

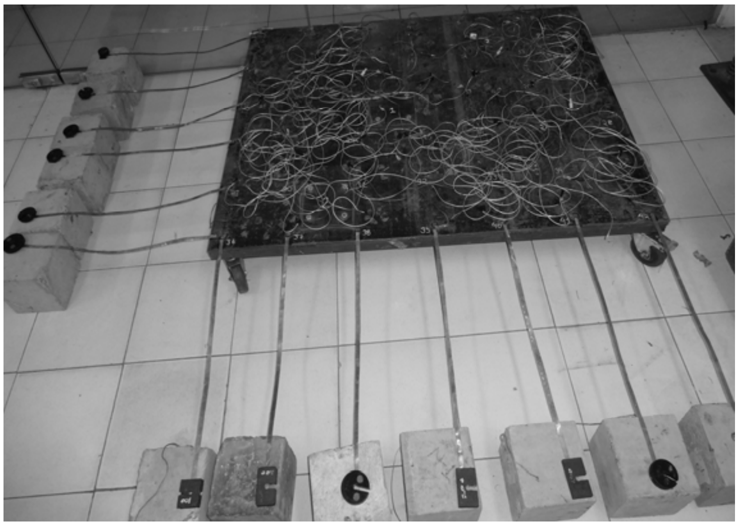

Figure 4 Whole Steel plate with metal wire set up

The plate has been divided in panels and on each panel the PZTs patches were attached, and for the metal wire the PZTs patches were attached at one end and the metal wire is attached along other end to the plate. The main advantage is this technique is we can remotely control the structure with the help of this metal wire technique. For the conventional method the total PZT numbers are 42, and we have to take (n x n) measurement which will take a long period. But with the help of the proposed technique we can easily detect the damage by 2n sensors where n is the number of the sensor grids (here 7). So the number of readings also get decreased and it is time saving too and mainly we can easily further use the metal wire along with the PZTs for other structures.

4. INDUCTION OF DAMAGE

In this experimental study, pre-emptive damage detection has been done in both the plate and metal wire is accomplished by using PZT patches of 10x10 mm^2 and LCR meter only [7]. A single hole of diameter 5cm was made at the 15^{th} panel of the plate which is shown in Figure 5. A cover plate as shown in the Figure 6 was placed over the damage, as a retrofitting measure and four 10mm diameter bolts were tightened at 30 N-m torque to get a repaired condition.

Figure 5 Damage location created at the 15th panel of the plate

For the both proposed metal wire technique and conventional EMI technique, the base line of the conductance signature was acquired from the PZT patches, which has been shown in Figure7 for both damaged and undamaged condition with the help of VEE Pro. 9.0. The repeatability of the signature is excellent as shown in the figure 7(a) and 7 (b). Damaged condition is being created by removing the repairing cover plate from the hole and then RMSD values from equation 1 is being calculated for each PZT patch.

Figure 6 (a) Retrofitting plate with four bolts of 10mm diameter,

Figure 6 (b) PZT patch attached on the steel plate

5. EXPERIMENTAL RESULTS

The RMSD values for conductance signature for each patch for steel plate have been calculated from the equation 1 and 2D bar graph has been plotted for steel plate and Figure 6 (a) shows the RMSD plot for steel plate using conventional approach. The same procedure has been repeated for metal wire also and the RMSD plot for the metal wire is shown in the approach

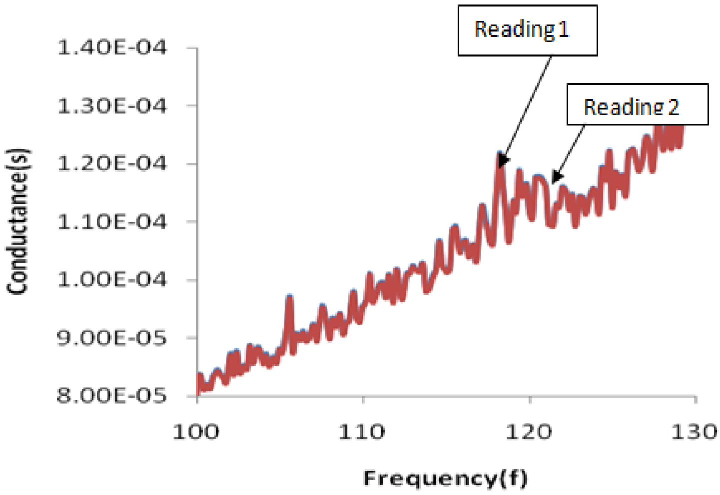

Figure 7(a) Repeatability test signature for 6th PZT patch for conventional technique

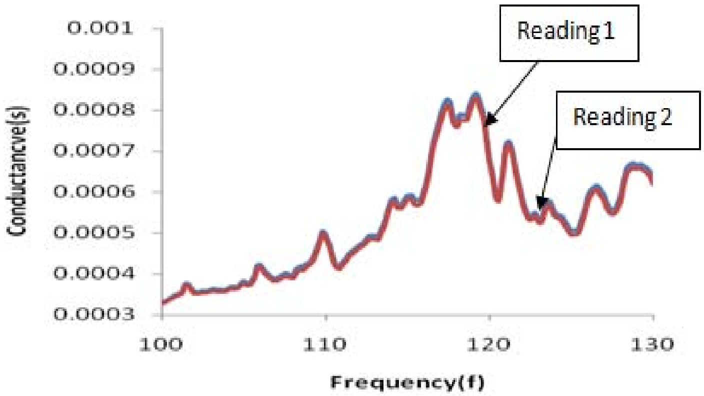

Figure 7(b) Repeatability signature for 6th PZT patch for metal wire technique

From the Plot we can easily see that for both the cases the damage has been detected for the panel no 15 where actually damage has been created. After comparing the two RMSD plots, both the methods are giving correct result. But for the metal wire technique, we do not need to calculate 42 panels, we can easily detect the damage from 14 sensors.

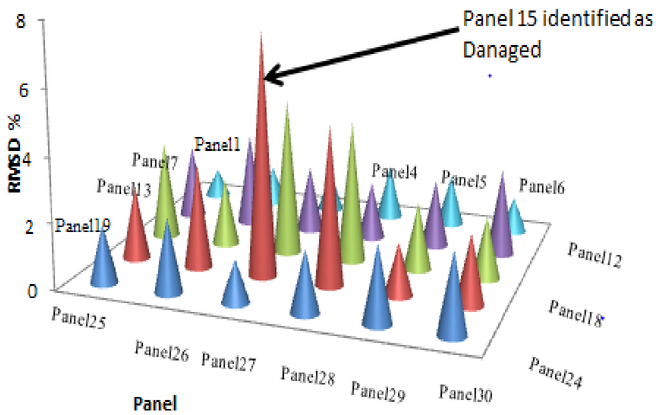

Figure 8 RMSD of signature at 30 panels acquired for steel plate

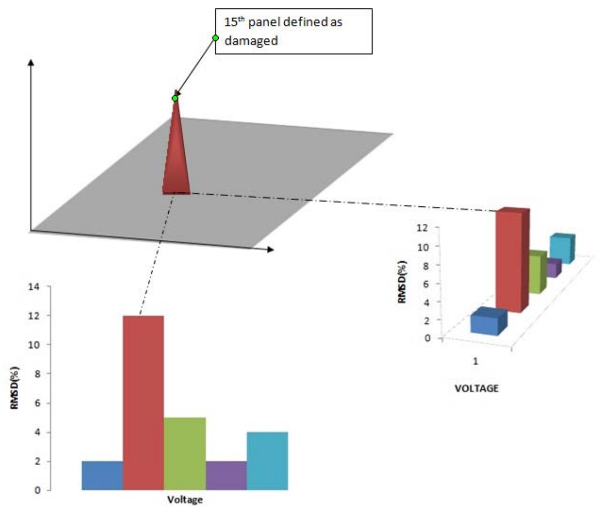

Figure 9 RMSD of signature plot for proposed metal wire technique

6. CONCLUSION

The results show that the damage detection effectiveness of the metal wire based EMI technique is comparable to the conventional EMI technique although much less sensors are needed. Thus, the proposed metal wire technique, which has much more advantages than the conventional technique, has proven its viability as a replacement of conventional technique. The time taken for using the metal wire technique is much lesser than the conventional one and these experimental results shows that metal wire technique can be used for the larger host structure also.

REFERENCES

[1] Bhalla. S and Soh. C. K. (2004), "Structural Health Monitoring by Piezo-Impedance Transducers I: Modeling", Journal of Aerospace Engineering, ASCE,17(4),154-165.

[2] Na. S, Lee H.K. "Steel wire electromechanical impedance method using a piezoelectric material for composite structures with complex surfaces", Composite Structures 98(2013).

[3] Naskar, S. and Bhalla, S.(2013), "Investigation into metal wire Based Variant of EMI Technique for Structural Health Monitoring", International Conference on Advances in Mechanical, Automobile and Aerospace Engineering (AMAAE-2013),Vol 6, No. 6 pp. 795-800

[4] Na, S. and Lee, H.K. "Resonant frequency range utilized electro-mechanical impedance method for damage detection performance on composite structures". Composite structure 2012:94(8); 2383-9.

[5] Agilent Technologies (2013)"Agilent VEE pro Quick start Guide" (www.agilent.com)

[6] Bhalla, S. (2001), "Smart System Based Automated Health Monitoring of Strcture", Master Thesis, Nanyang Technological University, Singapore.

[7] PI Ceramic (2013), http://www.piceramic.de.