Health Assessment of Civil Structures using Electromechanical Impedance Technique

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Abstruct -

Any civil structure require Health Monitoring with certain aging or after any repeated loading like earthquake. The EMI technique is a relatively new technique for SHM. The mechanical impedance Z of the host structure is function of the structural parameters viz. stiffness, the damping and the mass. Any damage to the structure will cause these parameters to change, resulting in change in mechanical impedance Z. Consequently, the electro-mechanical admittance $\overline{Y}$ will undergo changes, and serves as an indicator of the health of the structure. Due to high frequency of excitation, the EMI has very high sensitivity to damage, typically of the order of the ultrasonic techniques. The technique can detect flexural and shear crack before they can be conspicuously identified through naked eyes . In the EMI technique, a PZT patch is bonded to the surface of structure using high strength epoxy adhesive or embedded in structure whose health is to be monitored. The signature of the PZT patch is acquired over a high frequency range (30-400kHz) with the help of LCR meter or impedance analyzer. The signature is complex in nature, consisting of the real and the imaginary components called conductance and suspetance respectively. The signature in the healthy condition forms the reference signature. In future, when it is required to assess the health of structure, the signature is acquired again and compared with reference signature. Changes in signature from reference signature signify the crack/damage in the structure.

Keywords: Conductance Signature, Mechanical Impedance, PZT patch.

1-INTERODUCTION

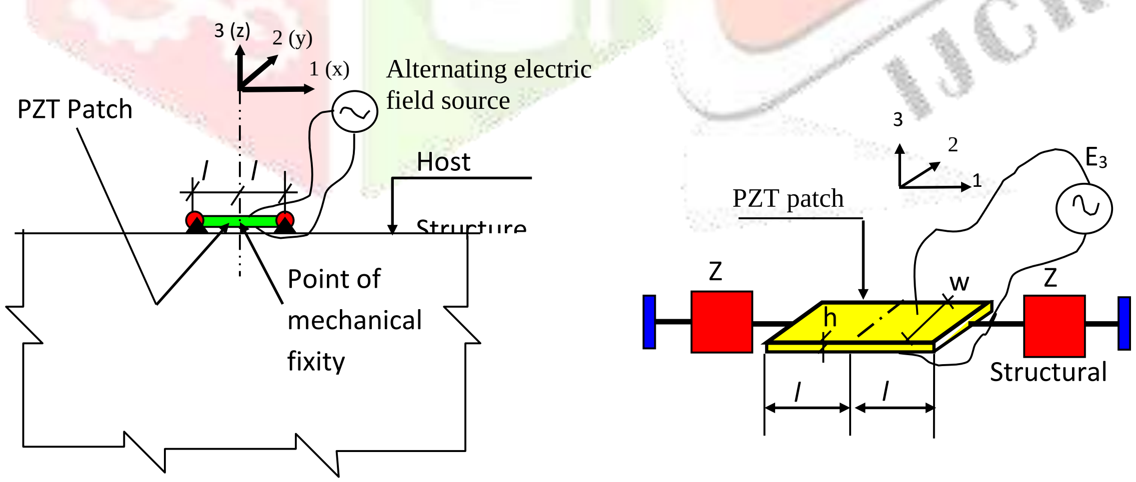
There are various techniques of health monitoring and damage/crack detection in Civil Engineering Structures. Damage/crack detection in structure is based on fact that any crack/ damage changes the structural characteristics like frequencies, stiffness, flexibility, mode shape etc. resulting in changes in the structural response. EMI technique is the smart technique of damage detectction. A system can be considered as 'smart' if it is able of recognize an external stimulus and respond to it in a predetermined way in a given time interval

(Ahmad, 1988). Besides it is expected to have the capability of identifying its status and may optimally adapt its function to external stimuli or give appropriate signal to the user. Smart structures have the capability to monitor their own condition, detect impending failure, control, or heal damage and adapt to changing environment.

2- ELECTRO MECHANICAL IMPEDANCE (EMI) TECHNIQUE

TheEMI technique is a relatively new technique for SHM. The technique was first developed by Liang et al. (1994) and later advanced by Giurgiutiu and his co-researchers (1997, 2000, 2002); Park (2000) and Bhalla (2004). In this technique, basically a PZT patch is surface bonded or embedded inside the structures that is required to be monitored, as shown in Fig. 2.2.The patch is assumed to be very small, possessing negligible mass and stiffness as compared to the host structure. When a PZT patch is subjected to an alternating electric field, it expands and contracts dynamically in direction ‘1’. Hence, two end points of the patch is subjected to equal impedance Z from the host structure. The patch (length 2l, width w and thickness h) behaves as thin bar undergoing axial vibration. An electro-mechanical model of the system is given in Fig. 2.2 (b), where the structure has been substituted with two equal mechanical impedances Z. The complex electro-mechanical admittance $\bar{Y}$ of the coupled system shown in this figure can be derived as (Liang et. al, 1994; Bhalla, 2004)

$$\bar{Y} = 2\omega j \frac{wl}{h}\left[\overline{\varepsilon_{33}^{T}} + \left(\frac{Z_a}{Z+Z_a}\right) d_{31}^2 \bar{Y}^E \left(\frac{\tan \kappa l}{\kappa l}\right) - d_{31}^2 \overline{Y^E}\right] \quad (1)$$



(a) (b)

Figure 2.2: Modelling PZT-structure interaction (Bhalla, 2004)

(a) A PZT patch bonded to structure under electric excitation

(b) Interaction model of PZT patch and host structure where d31is the piezoelectric strain coefficient of the PZT material, $\overline{Y^E}$ the complex Young's modules under constant electric field, $\overline{\varepsilon_{33}^T}$ the complex electric permittivity at constant stress, Za the mechanical impedance of the PZT patch, ω the angular frequency and κl is the wave number.

The electro-mechanical coupling represented by Eq. 1 is utilized in damage detection using EMI technique. The mechanical impedance Z of the host structure is function of the structural parametersviz. stiffness, the damping and the mass. Any damage to the structure will cause these parameters to change, resulting in change in mechanical impedance Z. Consequently, the electro-mechanical admittance $\overline{Y}$ will undergo changes, and serves as an indicator of the health of the structure. Due to high frequency of excitation, the EMI has very high sensitivity to damage, typically of the order of the ultrasonic techniques discussed previously (Park et al. 2003). The technique can detect flexural and shear crack before they canbe conspicuously identified through naked eyes (Bhalla and Soh, 2004a).

3-METHOD OF APPLICATION

In the EMI technique, a PZT patch is bonded to the surface of structure using high strength epoxy adhesive or embedded in structure whose health is to be monitored. The signature of the PZT patch is acquired over a high frequency range (30-400kHz) with the help of LCR meter or impedance analyzer.The signature is complex in nature, consisting of the real and the imaginary components called conductance and suspetance respectively. The LCR meter imposes an alternating voltage signal of one volt for root mean square to the PZT patch over the user provided frequency range. Higher voltage imposed to the PZT patch has no influence on the conductance signature, but might only be helpful in amplifying weak structural nodes (Sun et al., 1995). The signature in the healthy condition forms the reference signature. In future, when it isrequired to assess the health of structure, the signature is acquired again and compared with reference signature. Changes in signature from reference signature signify the crack/damage in the structure.

4-SELECTION OF FREQUENCY RANGE

Major drawback of global dynamic techniques is its low sensitivity in detecting hairline cracks and incipient damage because of the high wavelength stress. Sensitivity of any technique depends upon detection of hair crack/incipient damage. In the EMI technique, the excitation frequency is typically in range of kHz so that the wave length of the resulting stress wave is smaller than the typical size of the defect to be detected (Giurgiutiu and Rogers, 1997). The EMI technique acts best a frequency range from 30 kHz to 400 kHz for PZT patches 5 to 15mm in size (Park et al., 2003b). As the frequency increases, the sensing radius decreases. Frequencies greater than 200 kHz are favorable in localizing the sensing range. However, frequencies greater than 500 kHz are found unfavorable because the sensing region of the PZT patch becomes too small and the PZT signature shows adverse sensitivity to it own bonding condition rather than any damage to the monitored structure.

On the other hand, lower frequency range cover larger sensing region, which affect the sensitivity of technique. Giurgiutiu and Zagrai (2002) reported that piezo-impedance transducers do not behave well frequencies less than 5 kHz and technique loses its utility completely below 1 kHz.

5- **SENSING ZONE OF PIEZO-IMPEDANCE TRANSDUCERS**

Sensing zone of PZT patches depends upon the propagation of stress waves. Denser or non-homogeneous the medium like concrete, lesser the sensing region. Hence, the PZT patches have limited sensing zone based on properties of material, operating frequency. Park et al. (2000a) reported that the sensing radius of a typical PZT patch might vary anywhere from 0.4m on composite reinforced structures to about 2m on simple metal beams.

6- **ADVANTAGES OF EMI TECHNIQUE**

There are several advantages of EMI techniques which are summarized below,

(1) Basic feature of EMI technique is very sensitiveness to incipient damage. The sensitivity of the EMI technique is of the order of ultrasonic techniques. (Park et al., 2003a). This technique is applicable to every type of structure and each component of structure like tall buildings, tunnels, curved faced structures and foundation due to small size of PZT patches.

(2) This technique is resistant to mechanical, electrical, electro-mechanical noise due to high frequency range functionality. Due to this reason, its sensitivity is high.

(3) Since the same PZT patches act as actuator and sensor, this saves the number of transducers and the associated wiring.

(4) EMI technique is a cost effective method due to low cost of PZT patches. Typical cost of one PZT patches lies between USD $1 to USD $10.

(5) Since only PZT patch signatures are required to evaluate the health of structure, hence, online monitoring of structures is possible using this technique. Quick observation about the health of structure is possible using this technique, because extracted data from PZT patches do not require any type of transformation or complex processing.

(6) There is no bound of time in the application of this technique. Technique can be applied any time in service life of structure. However, it assesses the health after the installation time. It cannot extract the earlier history of structure. It uses the present information as benchmark to predict the health in future.

(7) There is no requirement of any type of modelling to monitor the health of structure. It saves the complex calculation and use of any type of software. Hence technique is very suitable for complex structures.

(8) Due to negligible mass of PZT patches, its stiffness is several orders below that of the monitored structures. Hence, application of this technique does not change the dynamic or the static behaviour of the monitored structure.

(9) Hardware used to measure the signature of PZT patches is very simple and portable and easily available commercially. Hence, it makes the technique cost effective.

7-LIMITATIONS OF EMI TECHNIQUE

(1) To apply this technique, a preplan is required. For example, it is impossible to implement this technique to detect the damage in foundation after construction, since the PZT patches cannot be installed after construction.

(2) PZT patches are very brittle and installation of patches requires skill and patience. Special attention is required to monitor these PZT sensors for deteriorations breaking. Once PZT patches are installed, they cannot be reused.

(3) PZT sensor has limited sensing zone, ranging from 0.4m to 2m only, depending upon the material and geometrical configuration.

(4) Due to limited sensing zone, large number of PZT patches will be required to complete monitoring of structures such as bridge, tall buildings and dams. One PZT patch contains two wires, hence there will be wiring problem.

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