EFFECT OF TEMPERATURE ON SIGNATURES OF PIEZO SENSORS FOR EMI TECHNIQUE AND ITS COMPENSATION

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ABSTRACT. The electro-mechanical impedance (EMI) technique is a signature-based technique for structural health monitoring (SHM). It is a well-known fact that the signature of the piezo sensors is very sensitive to the temperature fluctuation. This can, however, trigger a false alarm. Experimental investigations conducted in controlled environments do not require temperature compensation to be carried out. However, in real life situations, temperature effects cannot be ignored. This paper investigates the effect of the temperature on the signature of the piezo sensors and its compensation. The present study involves accounting temperature effects on piezoelectric transducers exposed to a controlled increase in environmental temperature. The amount of horizontal and vertical shifts in the signatures is quantified by using experimental data. Both horizontal and vertical shifts are found to be frequency dependent, the amount of shift increasing with frequency. Further studies shall formulate a simple algorithm for compensation based on the horizontal and vertical shifts aided by piezo sensors.

Keywords: Piezo sensors, Electromechanical Impedance (EMI) technique, Structural Health Monitoring (SHM), Temperature, Compensation.

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INTRODUCTION

All real-life structures are susceptible to damage due to various external and internal agents during their life spans. Thus, periodic maintenance is required to increase the functional life of the structures. Structural health monitoring (SHM) is a periodic monitoring of the structures for a safety point of view with the aim of identifying, locating and determining the severity of the damages in the structures. Also, it includes the determination of the remaining life of the monitored structure.Generally, any damage begins from an incipient stage but may finally result ina catastrophic damage over a period, if not treated on time. Thus, it is necessary to determine the damage in its early state to avoid its further propagation. The electro-mechanical impedance (EMI) techniqueuses smart materials i.e. lead zirconatetitanate (PZT) patches to capture such type of damage.

Smart materials are those materials which are able to change the physical properties in a specific manner due to a certain specific type of stimulus input. Some common types of smart materials arepiezoelectric materials, shape memory alloys, optical fibre, electro-rheological fluids etc. Piezoelectricity is derived from the Greek word *Piezo* which means to squeeze, thus the electricity generated by squeezing is piezoelectricity (Harper 1883). The piezoelectric behaviour was first studied by the Curie brothers extensively in the late 19^{th} century. Until now the researchers have invented several artificial crystals showing piezoelectric behavior other than the naturally occurring crystals. Commercially, two most common forms are PZT and Polyvinylidene fluoride (PVDF) flexible composites.PZT patches have higher strength and stiffness than PVDF.PVDF is ductile and has shape conformability whereas, PZT is brittle and not acquiescent with curved surfaces.

ELECTRO-MECHANICAL IMPEDANCE (EMI) TECHNIQUE

The EMI was first invented by Liang et al. (1994). It is a non-destructive technique which uses piezo sensors for condition monitoring of the host structures. A PZT patch acts both as an actuator and a sensor. When it acts as the sensor, it functions in direct mode in which it generates electric potential on the application of stress. In converse effect, it produces stress when an electrical signal is applied across its surface.In EMI technique thePZT patches bonded on the structures are electrically excited at a higher frequency in the range of 30-400 kHz by an impedance analyzer or an LCR meter. At this frequency range, the PZT patchesactuate the structure and then senses the response reflected back from the structure in the form of an admittance signature. These signatures consist of a real part which is known as conductance (G) and an imaginary part known as susceptance (B). Any damage to the structure reflects a deviation in the admittance signature which is recorded in the frequency domain. Sincethe EMI technique uses a very high-frequency range, is capable of detecting damages in insipient stage and also immune to other low-frequency structural vibrations. However, these signatures are sensitive towards the change in the surrounding temperature. Several researchers have proposed methods to compensate for these changes from the obtained signatures. Next section covers past work on a study of the temperature effect.

TEMPERATURE EFFECT ON PIEZO SENSORS

Krishnamurthy et al. (1996) found a decrease in the magnitude of the impedance peaks of a free PZT patch due to the increase in temperature. They choose a range of 25 to 75 °C in which the dielectric and piezoelectric properties of piezo ceramic PSI-5A shows a linear trend.Though it is nonlinear at a border temperature range. Normalization of the variation of impedance with temperature eradicates the effect of a change in magnitude of impedance which makes the variation independent of frequency. Changes in temperature, boundary condition, loading effects etc. lead to a variation on the susceptance signature whereas little change in the conductance signature. Insignificant change in the resistive portion of electrical impedance suggests utilization of real part of electrical admittance for the damage response which minimizes the effect of temperature

Park et.al 1999 found significant horizontal and vertical shift in signatures due to a temperature in contrast to damage where the shifts are irregular. Empirical temperature compensation technique was developed which can be applied in a complex structure. Compensation technique was validated ona bolted pipe joint, a gear, and a composite reinforced aluminum plate along with the experiments.

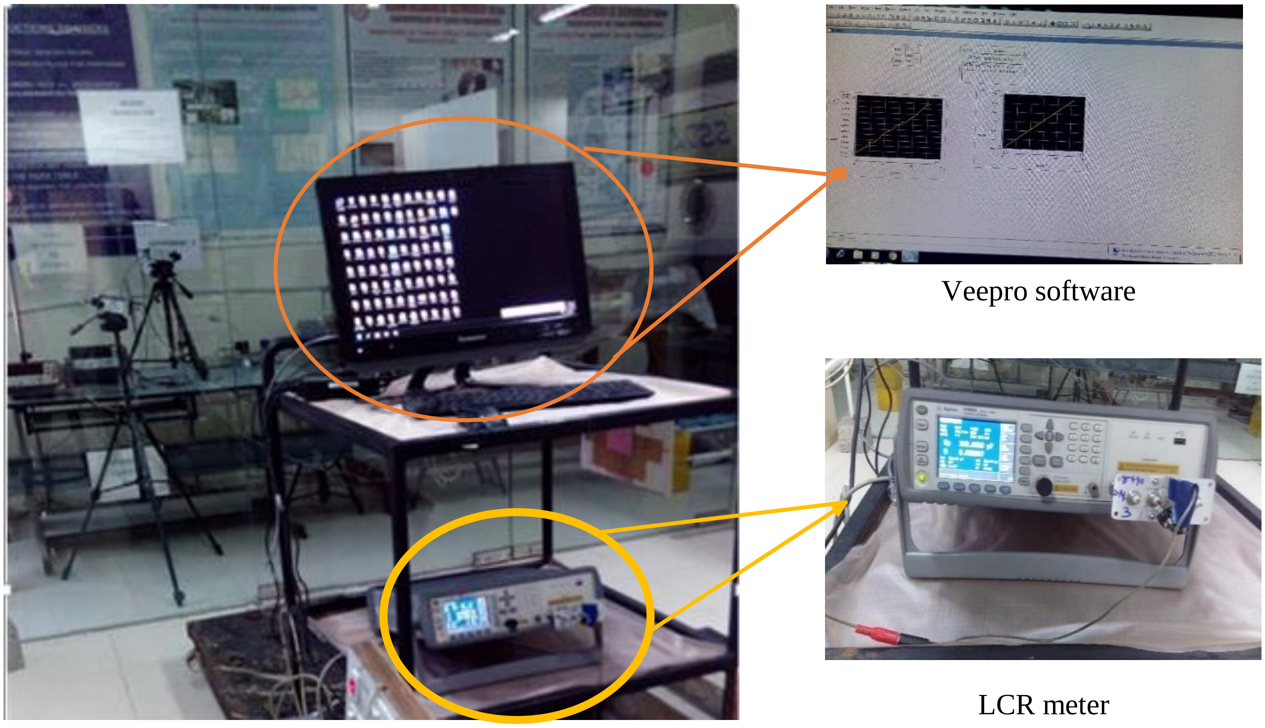
The experiments conducted in lab controlled environment gives the stable results but in actual field condition, it is not possible due to the fluctuation of temperature (Bhalla 2001). He performed the simulation study of each parameter controlling another parameter in which he found the horizontal shift in the signature is due to change in Young's modulus of the structure and vertical shift is due to the change in ε_{33} and d_{31}.

Structural peaks are more affected rather than the PZT peaks on various temperatures (Yang et. al.2008). The shift of PZT resonance towards left is mainly due to the softening if the bonding layer, structural properties and piezoelectric properties PZT patch. Through simulation on FE software ANSYS, he validated the shift of the signatures is caused by a reduction of stiffness of the bonding layer against increasing temperature.

The variations in the amplitude of the impedance signatures were related to the temperature-dependence of the capacitance of the piezoelectric sensor (Baptista et al. 2014). As a result of temperature variation, the shift in the resonance peak is not constant but increases with the increase in the frequency.The frequency band used to calculate the damage indices played an important role in compensating for temperature effects by maximizing the correlation coefficient. Next section describes temperature related lab study aiming at the development of a raw simple compensation algorithm.

EXPERIMENTAL PROCEDURE

For the experiment, a piezo sensor of 10 × 10 × 0.3mm was surface bonded on an aluminum plate of 200 × 25 × 2mm using a two-part epoxy adhesive. Signatures were acquired through Agilent E4980A LCR meter using VEEPRO platform at the lab temperature. For the temperature range of 30-60 °C, the structure was placed on the oven and signature was acquired at an interval of 5°C increase in the temperature. Figure 1 shows the complete setup of the experiment.



(a)

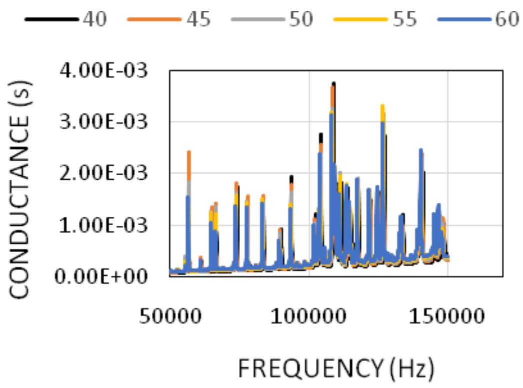
(b)

(c)

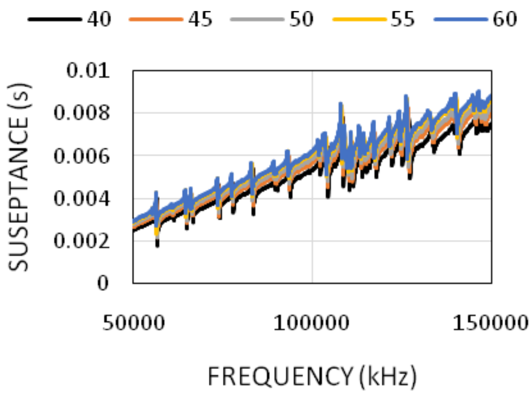
Figure 1 Complete set up of the experiment
(a) LCR meter and controlling PC
(b) Specimen inside oven
(c) Oven

OBSERVATIONS

Figure 2 shows a plot of the conductance and susceptance signatures in 50-150 kHz range.



(a)



(b)

Figure 2 Signature plot for various temperature (a) Conductance (b) Susceptance

It is observed that both the conductance and susceptance signatures shift towards the left with the increasing temperature. The shift of the signature was computed horizontally by the iteration and vertically the average shift at each frequency point. Figure 3 and 4 below show the nature of shift horizontally and vertically.

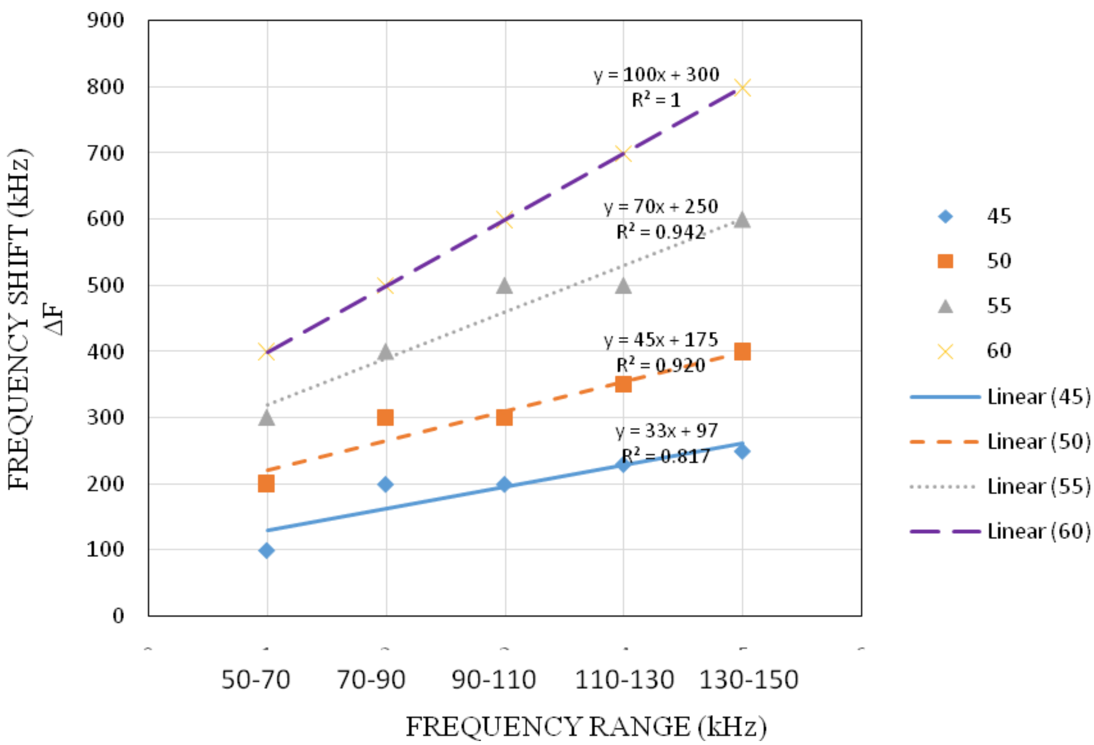


Figure 3 Horizontal shift as a function of frequency

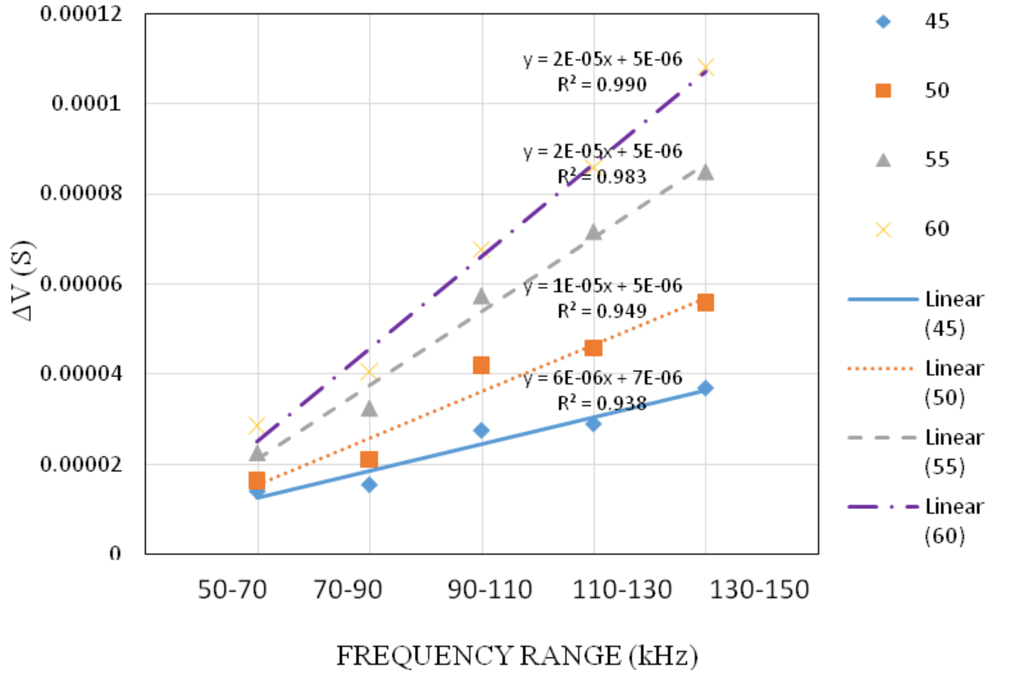


Figure 4 Vertical shift

Figure 5 represents vertical shift as function of temperature for various frequency intervals. The shift shows a linear variation with increase in the temperature for all the frequency changes. However, the slope of the curves increases for the higher temperatures.

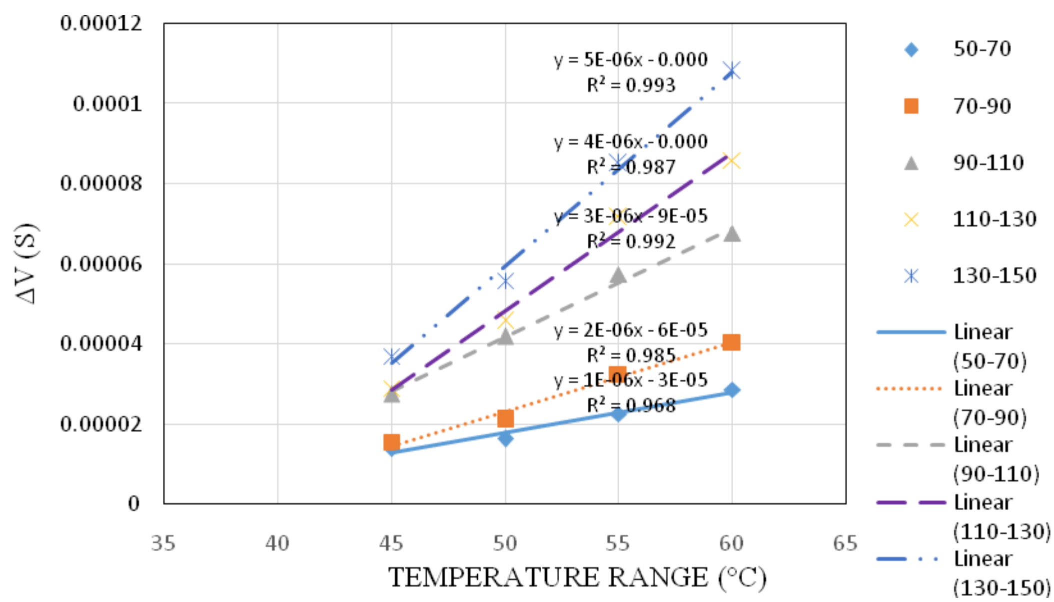


Figure 5 Vertical shift vs temperature for different frequency ranges

From fig 3 to 5, it is clearly observed that both horizontal and vertical shifts are frequency dependent, the amount increasing with frequency. This fact shall be incorporated into the raw compensation technique to be formulated by the authors.

CONCLUSIONS

This paperhas presented initial experiments conducted to study the effect of temperature on conductance signatures. The study finds a strong dependence of shifts on temperature and frequency. Based on these observations, a new compensation technique shall be formulated which will also utilize the signature of free PZT patches. Results shall be published in the next paper.

REFERENCES

1. Harper, D. (1883), "Piezoelectric", Online Etymology Dictionary.

2. Liang, C., Sun, F. P. and Rogers, C. A. (1994), "Electro-Mechanical Impedance Modelling Of Active Material System." Smart Material and Structures, Vol. 5, No.2, pp. 171-186.

3. Krishnamurthy, K., Lalande, F., and Rogers, C.A., (1996), "Temperature Effects on Piezoelectric Elements Used as Collocated Actuator/Sensors," Proceedings of SPIE North American Conference on Smart Structures and Materials, Vol. 2717, pp. 302-310.

4. Park, G.,Kabeya, K., Cudney, H. H. and Inman, D. J. (1999),"Impedance-based structural health monitoring for temperature varying applications." JSME International Journal, Vol.42, No.2, pp.249-258.

5. Bhalla, S. (2001),"Smart System Based Automated Health Monitoring of Structures"M. Eng. Thesis, Nanyang Technological University, Singapore.

6. Yang Y., Lim Y. Y., and Soh C. K. (2008),"Practical issues related to the application of the electromechanical impedance technique in the structural health monitoring of civil structures." Smart Material and Structure. 17,035008.

7. Baptista, F. G., Budoya, D. E., Dealmeida, V. A., and Ulson, J. A. C., (2014), "An Experimental Study on the Effect of Temperature on Piezoelectric Sensors for Impedance-Based Structural Health Monitoring." Journal of Sensors 14, 1208-1227.