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Smart Monitoring System for Detection of Damage in Structural Parts by EMI and ANSYS

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Abstract - *Electromechanical impedance techniques are commonly used in recent structural health monitoring systems for damage detection. The technique is accurate and reliable for the detection of damage and provides an alert about structure deterioration by accessing the measured parameters. Piezoelectric patches are bonded to the structure for damage identification. A smart system has been proposed in this paper to detect damage in the structure of concrete beam, metal plate, and pipeline with impedance chip and piezo sensors. A similar structure of concrete beam, metal plate, and pipeline were designed using ANSYS. The signatures obtained from the impedance chip were compared with the output from ANSYS. The result from the impedance chip indicates the detection of damage due to cracks, corrosion, boundary condition, deformation, and leakages. The impedance obtained from the chip has a good agreement with the ANSYS results.*

Keywords: *Smart Structural Monitoring, Damage, Electromechanical Impedance, Piezoelectric Patch, ANSYS.*

I. INTRODUCTION

Recent researchers have utilized smart systems in Structural Health Monitoring (SHM) for damage detection. Therefore mechanical and civil structures are to be monitored using smart materials like piezoelectric materials. Electromechanical Impedance Technique (EMI) is a technique that uses Lead Zirconate Titanate (PZT) smart transducers to detect the damage. This technique is advantageous due to its lightweight, less cost, low power consumption, sensing capability, and real-time applications [1]. PZT actuators assimilated with mechanical systems to determine the consumption of power and transfer of energy in electromechanical systems. The electromechanical admittance can be given by the analytical method in terms of impedance [2, 3]. The objective of this research article is to identify the smash-up parts in various civil construction structures with accuracy and to compare the data with similar simulated structures by ANSYS.

II. LITERATURE REVIEW

Recently there are three methods used to measure the impedance corresponding to damage using bonded PZT. Inductance, Capacitance and Resistance (LCR) meter, impedance analyzer, and impedance chip. Zhou et al. proposed two dimensional EMI model from the extension of the one-dimensional model using piezoelectric actuators in thin plates and shells using the analyzer. This model can be applied to both two and one-dimensional structures [4]. This model was updated, and the impedance values were extracted from conductance and susceptance measurements using an impedance analyzer [5, 6]. An EMI was predicted by a generic model by the interaction of piezo ceramic with the structure [7]. A generic three-dimensional model was proposed by considering the mass of adhesive and PZT bonded to the structure [8, 9]. Qing et al. proposed the effects of adhesive in the measurement of impedance by impedance analyzer effectively at higher frequencies. The sensitivity of the sensor signal can be affected by the thickness of the adhesive used in the structure [10]. Bhalla et al. proposed a model assimilating the effect of shear lag into electro-mechanical admittance [11].

The electrical impedance can be influenced by the effect of temperature on the sensors. There exists a strong relation of temperature with frequency [12]. Djema et al. used the finite element method to investigate the temperature effects using the EMI technique for monitoring the structural health [13]. Na detected the reduction in the wall thickness of the metal pipeline using EMI. The resonance peak was found to be shifted in the impedance signature [14, 15]. The early hydration of concrete was monitored with the piezoceramic embedded into it using EMI. The variation in conductance peak and root mean square deviation provides the information of hydration in the concrete structure [16]. The strength of the cementitious material was monitored using the EMI technique by conductance signatures [17]. The embedded piezo sensor employs the EMI technique inside cementitious material for the measurement of strength by impedance analyzer [18]. Parl et al. monitored the pipeline structure by unfastening bolts for damage detection. Impedance was measured by an impedance analyzer [19, 20]. An experiment on the pipeline was conducted by the loosening of bolts using sensors with less power consumption. The pipeline structure monitoring due to corrosion was proposed [21, 22].

The advantages of impedance chip over impedance analyzer or LCR meter are cheaper and small size with a range of frequency 1KHz. AD5933 chip is a miniature evaluation board that is connected to the piezo sensor and personal computer through Universal Serial Bus (USB). Any structural change is identified by the variations in the measurement of impedance by impedance chip. The chip consists of a frequency generator on board with 12 bit and 1 Mega Sample Per Second (MSPS) analog to digital converter. The system clock frequency is 16MHz with an accuracy of 0.5% [23].

The performance of prototype steel/ reinforced concrete structures was evaluated using an impedance chip [24]. The external impedance is excited at a particular frequency by the function generator. A calibration resistor of 200kilo ohm is added each time for proper impedance measurement at various frequency ranges. It is measured at various frequency ranges when a calibration resistor of 200kilo ohm is added. Quinn et al. proposed a wireless device with AD5933 to monitor the concrete curing, and a comparison of results was made with an impedance analyzer [25]. Na and Lee used AD5933 for damage detection of composite plates, which covers a larger surface area [26].

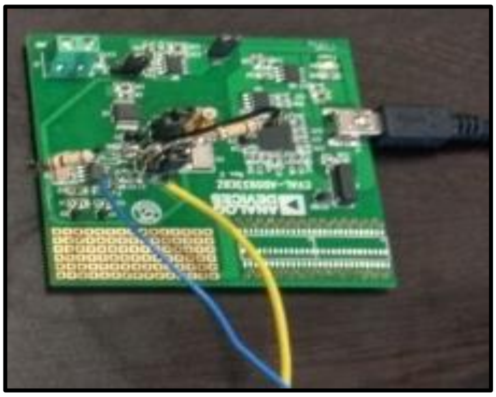

Fig. 1: Impedance Chip

Finite element analysis software ANSYS 18.0 was used for the simulation results in the proposed method. The PZT was bonded to the structures like the metal plate, concrete, and Galvanized Iron (GI) pipeline. The PZT and the structure are glued for coupling the displacements. To obtain the symmetrical nature, only a quarter of the structure was modeled. Solid5 Element was adapted for performing both the electrical and mechanical fields [27]. The harmonic analysis was performed to get the EMI of the transducer. The current flow was calculated by harmonic excitation, and hence EMI was obtained for a particular range of frequency with a certain step size [28]. LCR meter and impedance analyzer were used for the EMI technique. The disadvantage of this method was the high cost and bulky size. The EMI technique was developed on the microcontroller-based digital direct synthesizer for measurement of damage. In this method, the circuit was complex, and error chances were high.

III. OBJECTIVE

The main objective of this paper is to identify the damage in various civil and mechanical structures with an accurate and cost-effective method using an impedance chip. Comparing the data obtained from the chip in prototype structures with the similar simulated structures based on ANSYS software.

IV. METHODOLOGY

Different structures have been used for the experimentation. The structures used were concrete beam, metal plate, and GI pipeline. A piezo sensor was bonded to these structures using epoxy resin. A concrete beam of size 500 x 100 x100 mm was considered, and the piezo sensor was bonded to the structure with epoxy resin. The output from PZT was measured from the impedance chip and considered as the base dimensions. Force was applied to the concrete beam, and the corresponding impedance was measured from the chip. The same structure was designed in ANSYS software, and the same force of 5KN was applied to the structure, and the corresponding impedance was measured using ANSYS software. The damage was detected by using both impedance chip and ANSYS. Figure 1 shows the impedance chip with the calibration resistor. Figure 2 shows the experimental structure of the concrete beam bonded to the piezo sensor with the impedance chip. Figure 3 shows the ANSYS design of a concrete beam with a piezo sensor glued to it.

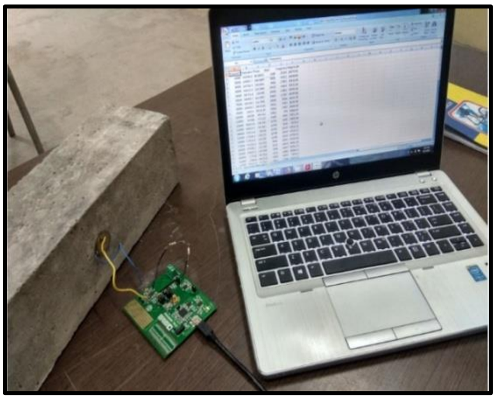

Fig. 2: Impedance Measurement of Concrete Beam using Impedance Chip

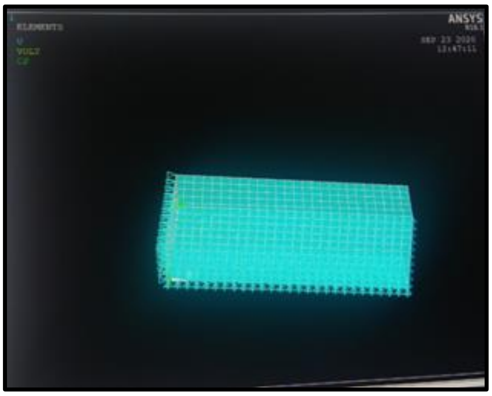

Fig. 3: Impedance Measurement of Concrete Beam using ANSYS

Fig. 4: Impedance Measurement of Metal Plate using Impedance Chip

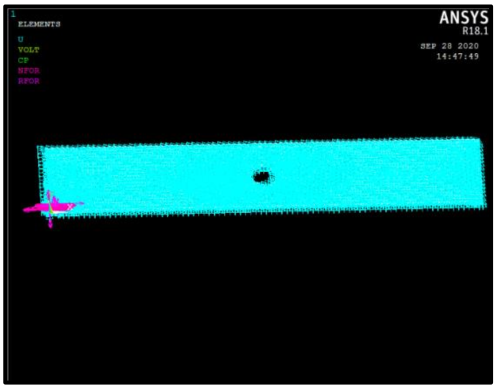

Fig. 5: Impedance Measurement of Metal Plate using ANSYS

A metal plate made of mild steel of size 550mm x 400mm x 2mm was chosen for the proposed work. Piezo sensor was bonded to the structure using epoxy resin. Impedance was measured by using an impedance chip without any damage to the metal plate and considered as the base value. Damage in the metal plate was created by drilling a hole of 20mm in the middle. The output was measured from the PZT using an impedance chip. The same design was made in ANSYS software, and the output impedance was measured. Figure 4 shows the experimental structure of the metal plate bonded to the piezo sensor with the impedance chip. Figure 5 shows the ANSYS design of the metal plate with a piezo sensor glued to it.

Pipeline made of galvanized iron of diameter 20mm was chosen for the proposed work with a height of 330mm. PZT was bonded to the structure using epoxy resin. Nuts were used to combine the two pipelines of a given length. Nuts were tightened, and impedance signature was measured and considered as the base value. Nuts are loosened, and the damage was detected using an impedance chip from piezo sensors. The same design was made in ANSYS software, and an impedance measurement was calculated. Figure 6 shows the experimental structure of the GI pipeline bonded to the piezo sensor with the impedance chip. Figure 7 shows the ANSYS design of the GI pipeline with a piezo sensor glued to it.

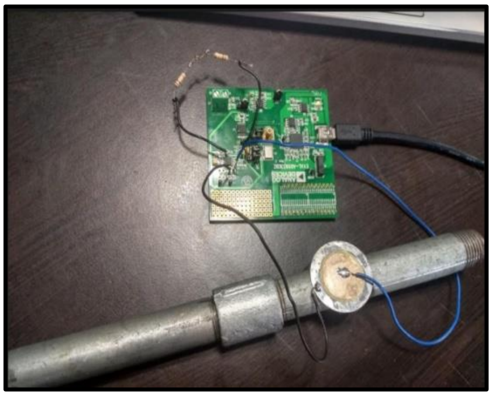

Fig. 6: Impedance Measurement of Pipeline using Impedance Chip

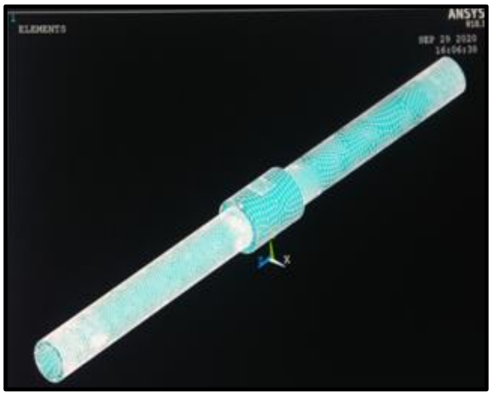

Fig. 7: Impedance Measurement of Pipeline using ANSYS

V. RESULTS

Figure 8 shows the comparison of conductance signatures of concrete beam obtained from impedance chip and ANSYS with respect to frequency. Force of 5KN was applied to the concrete beam to create the damage in the beam. The conductance was calculated from the impedance chip by user-defined software. The peak value of conductance was noted at the output of the impedance chip. The design of concrete beam was designed in ANSYS software, and the conductance value measured from the ANSYS shows the approximate peak at the same frequency as that of the impedance chip. The Peak in the conductance signature indicates the damage in the concrete beam at the same frequency. Impedance chip and ANSYS show a relative comparison of conductance signatures for SHM of concrete structures.

Figure 9 represents the comparison of conductance signatures with frequency for metal plate using impedance chip and ANSYS. The output from the chip measured from the piezo sensor was compared with the ANSYS software, and found the damage detected by the chip shows a similar variation with reference to the ANSYS software. The metal plate was damaged by drilling a hole in the middle of the plate. The conductance was measured from an impedance chip, and the same design was made in ANSYS software. The results indicate the detection of damage at the same frequency in the case of the metal plate.

Repetition of the process was carried out to check the result accuracy of the chip.

Figure 10 indicates the comparison curve between conductance and frequency for the GI pipeline. Piezo sensor was bonded to the pipeline, and the same system was designed using ANSYS software. The conductance peak determines the damage detection and is verified by ANSYS software.

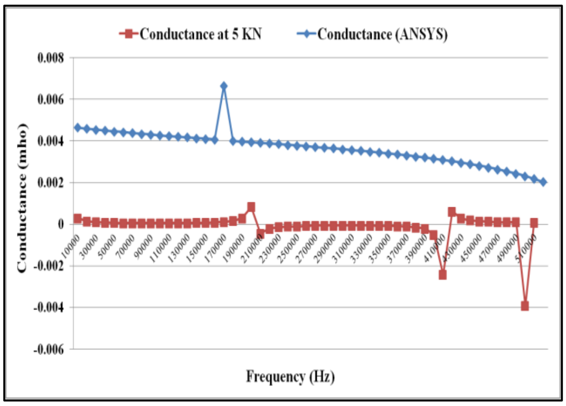

Fig. 8: Conductance Signatures Vs. Frequency of Concrete Beam

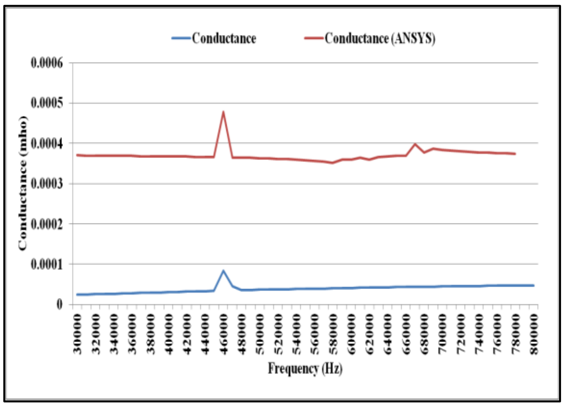

Fig. 9: Conductance Signatures Vs. Frequency of Metal Plate

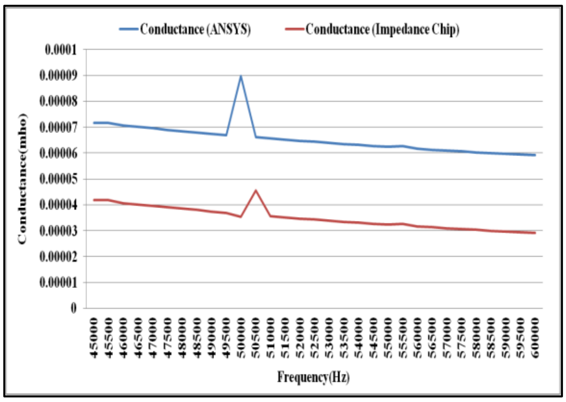

Fig. 10: Conductance Signatures Vs. Frequency of Pipeline

VI. CONCLUSION

The objective of identifying the damaged parts in various construction material structures were carried out accurately and compared the data with simulated structures by ANSYS.

- From the final results, it was observed that the peak frequency measured from the impedance chip was in good agreement with the output measured from ANSYS.
- Comparison of using both hardware and software implies that the impedance chip was reliable and accurate for damage detection in civil and mechanical structures.
- The main merits of impedance chips are their low cost, small size, damage assessment, and remote monitoring.

The future scope of this work will concentrate on optimization and the internet of things.

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