Experimental Study on Isotropic plate with Piezoelectric Sensor under Force Vibration

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Abstract*- Structural Health Monitoring (SHM) has great potential for enhancing the functionality, serviceability and increased life span of the structures, which contributes significantly to the economy of the nation. This work is aimed at the forced vibration analysis of an isotropic plate using piezoelectric materials. The experimental investigation on the plate specimen is carried out which employs a surface-bonded lead zirconatetitanate piezoelectric ceramic (PZT) patch for structural health monitoring and nondestructive evaluation. The experimental analysis is undertaken on thin plate and thick plate specimen and the signature obtained for the healthy state and damaged state of plate is studied. On comparing the results obtained it is found that this technique of structural health monitoring using piezoelectric materials is more advanced for obtaining timely damage detection of the structure.*

Keywords*-* Plate, Piezoelectric Materials, Structural Health Monitoring, Vibrations.

I. INTRODUCTION

Major civil infrastructural systems such as bridges, dams, offshore structures, buildings etc. constitute a significant portion of the national wealth. Now, the ageing of these structures is creating maintenance problem. The maintenance costs of these structures is high, and even a small percentage reduction in the maintenance cost amounts to significant saving. Early detection of problems, such as, cracks at critical locations, corrosion, damages etc., can help in prevention of catastrophic failure and structural deterioration beyond repair. SHM of civil infrastructures is of considerable importance in view of the immense loss of life and property that may result from structural failure. The unique feature of large size and complexity of most civil infrastructures renders visual inspection very tedious, expensive, and sometimes proves unreliable. The need for quick assessment of the state of health of civil infrastructures should be given has research attention for the development of an automated, real-time, and in situ health monitoring technique. Existence of structural damage in an engineering system leads to modification of the vibration modes. Failures of bridges, buildings and dams are common due to the vibration caused by earthquakes or with vibrations caused by wind loads. This explains the necessity to understand vibration behavior of various systems and reduce vibrations by designing suitable control mechanisms. Accurate Condition Assessmentof civil engineering structures has become increasingly important. Due to the prominent role of plates in civil, aerospace and mechanical structures, extensive research has been conducted on their behavior and their analytical formulation during the last decades. With the advancement of technology, new kinds of material and technique have been introduced into construction.

Smart structures and materials can be a solution to these problems as they possess adaptive capabilities to external stimuli. Piezoelectric materials are very common example of such materials. A piezoelectric material is a crystal in which electricity is produced by pressure (Direct Effect). Conversely, a piezoelectric material deforms when it is subjected to an electric field (Converse Effect). The piezoelectric sensor senses the external disturbances and generates voltage due to direct piezoelectric effect while piezoelectric actuator produces force due to converse piezoelectric effect which can be used as controlling force. These techniques allow the system to monitor its own structural integrity while the infrastructures are in service, and also the monitoring throughout the service life of the infrastructures. Such a SHM system is useful not only to improve reliability but also to reduce the costs of maintenance and inspection for infrastructural systems. (Bhalla, Chee, 2004) investigates to extract the effective drive point (EDP) impedance of the host structure from the experimentally measured conductance and susceptance signatures.(Chhabra, Bhushan, and Chandna, 2013) studied vibration suppression for simply supported plate with piezoelectric patches in optimal positions using Linear Quadratic Regulator Scheme.Faizal (2004) Condition assessment of the structures using low frequency technique on a 2m and 4m Reinforced concrete beam and rectangular hollow section steel frame. Damage induced Analysis is done in 3D modeling in computational analysis it has to be checked with the experimental modal analysis. (Gulizzi, Rizzo, Milazzo and Ribolla, 2015) uses advanced signal processing to perform damage detection based on the combined and simultaneous application of guided ultrasonic waves and electromechanical impedance. The development and application of damage detection strategies and the continuous health assessment of concrete structures have become a matter of ultimate importance. Impedance based model is found to be effective for health monitoring of structures (Khante, Sangai, 2014). Active vibration control on the flexible structure with piezoelectric materials was studied by (Narwal, Chhabra, 2012). (Kale, Ghosh, 2014)with sensors and actuators and the active controller was designed to control first three modes of vibration of plate.(Michael, Ahmed, Xianfei andJoel, 2010) investigated sensor network on Voigt Highway Bridge. (Sathyanarayana, Raja and Ragavendra, 2013) finds the influence of damage on sensor correlation and it is observed that the presence of damage has significantly modified the interpreted engineering parameters from the PZT patch and if they are appropriately correlated with respect to healthy structure, then the occurrence of damage related information will be ascertained.

The interest in the ability to monitor a structure and detect damage at the earliest possible stage gives research attention in the area of automated SHM and non-destructive evaluation of structure. This paper aims to experimentally carry out the healthy signature of an isotropic plate and the signature of the damaged plate and study the results obtained from both the condition. In this study, the investigation was carried out on two plate specimen using piezoelectric ceramic patch, digital oscilloscope. The ultimate goal of this research is to enable systems and structures monitor their own integrity while in operation and throughout their design lives.

A. Piezoelectricity and Piezoelectric materials

Piezoelectricity is a phenomenon in which mechanical energy is converted into electrical energyand vice versa. A material possessing piezoelectricity will generate an electrical charge when a mechanical pressure is applied to it and the material will experience a geometric change when an electrical charge is applied to it. There are a few natural materials that exhibit piezoelectricity, of which piezoelectric ceramics (Lead ZirocondateTitanate, PZT), piezoelectric polymers (PolyvinylideneFluoride, denoted as PVDF) and Piezoelectric Ceramic/Polymer Composites are frequently used piezoelectric actuators and sensors for structural health monitoring and structural repair.

B. Effects of Structural Damage on Frequency

The presence of damage in a structure causes changes in the natural frequencies of the structure. Quantitative knowledge of frequencies, damping and mode shapes associated with structural response aids in the understanding how forces are generated and transmitted which allows intelligent evaluation of vibrations in the structure. The most useful damage location methods (dynamic testing) are those using changes in resonant frequencies because frequency measurements can be quickly conducted.

C. Low Frequency Technique

Low frequency techniques are based on the analysis of structural dynamic response measurements, generally made by subjecting the structure to low frequency vibrations. From this analysis, a suitable set of parameters can be identified, and any variation in these parameters is used significantly as an indication of the changing state of the structures. Damage in a structure alters its modal parameters, namely the stiffness matrix and the damping matrix .In these techniques, the structure is excited by appropriate means and the response data is processed to obtain a set of indices representative of the condition of the structure.

II. EXPERIMENTAL INVESTIGATION

Experimental investigation was carried out on square plate in simply supported condition in two stages of undamaged (healthy) state and damaged state. In the first stage, the responses for the healthy state was taken and in the second stage the plate was damaged in different levels and the test was carried out for each level of damaged.

A. Materials and Specimens

Two plate of size 300 mm X 300 mm X 5mm and 300 mm X 300 mm X 16mm were considered as the test specimen. The piezoelectric material used is piezoelectric-ceramic i.e. PZT patch is circular in shape. PZT patch consist of an outer layer of 27 mm diameter and inner layer of 19 mm diameter having negative and positive charge respectively and about 1 mm thick. Adhesive used for bonding PZT patch with the host structure was Fevi-Quick. Digital storage oscilloscope (DSO) was used as a data analyzer for structural frequency response. Constant load assembly (hammer machine) was employed to create dynamic loading on the plate by applying constant load at constant time interval. The signal of the PZT patch was made strong using a design amplifier.

B. Experimental Set-up

The study was undertaken to analyze the effectiveness of the PZT patch for damage detection and health monitoring if the plate under consideration. The investigation essentially involved an isotropic plate (host structure) with surface-bonded PZT patch, DSO and its cables, amplifier and a constant load assembly (hammer machine). Fig. 1 shows the experimental set-up.

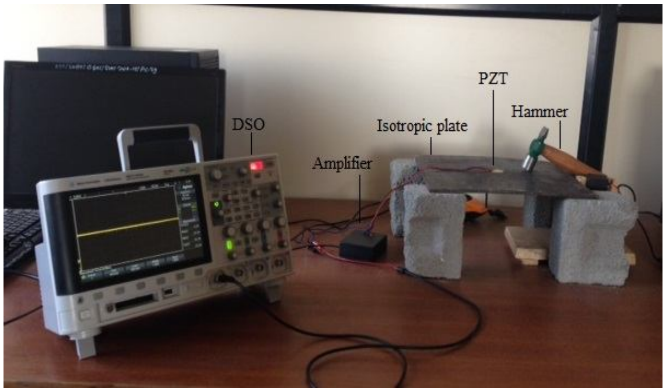


Fig. 1 Experimental Set-up.

The plate was considered in simply supported condition and the PZT patch was bonded at the center of the plate with adhesive. The PZT patch was soldered and attached to the instrumentation amplifier for strengthening the signals obtained on the oscilloscope as the patch is sensitive to gives signal for the external disturbances occurring in the structure. The soldered patch and amplifier was connected to the oscilloscope with crocodile cables and was inserted in channel. DSO provides a response in the form of signals to the vibrations generated in the plate due to the hammer machine. This response is can be taken in voltage vs. time and in frequency domain or Fast Fourier Transform (FFT).

1) Experimentation on Healthy Plate: In level 1, the host structure with PZT patch was analyzed in healthy state (Pristine state) with the help of digital oscilloscope and the response was recorded. In this case PZT patch was acting as a sensor and it was sensing the changes occurring in the host structure. Vibrations were induced in the plate by constant load applied at constant time interval. Oscilloscope was triggered for every millisecond and response was obtained through PZT patch in voltage vs. time and FFT of the host structure for healthy state.

2) Experimentation on Damaged plate: In level 2, the host structure with the PZT was analyzed in damaged state and the damages were given to the plate in different state of damage. For the first state of damage or incipient damage, 2 holes were induced on the host structure. For the second state of damage or moderate damage, 4 holes were induced and for the third state of damage or severe damage, 8 holes were induced on the host structure. The size of hole, minimum edge and end distance were taken from IS 800-2007. Experiment was carried out for various states of damage and the response was obtained.

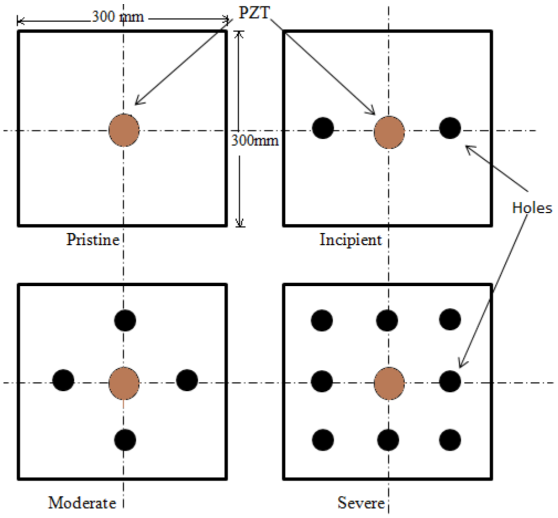


Fig. 2 Various level of damage induced in the plate.

III. RESULTS AND DISCUSSION

A. Response for Pristine State

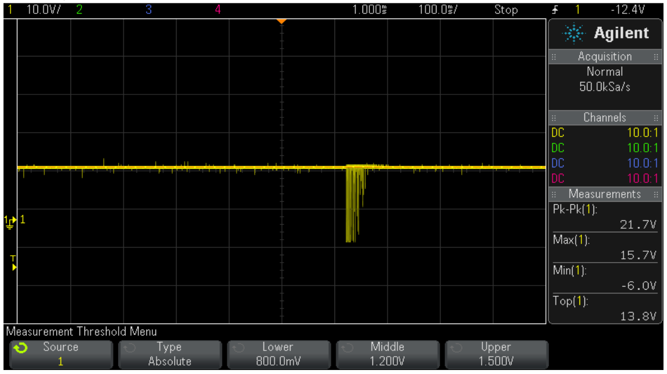
Firstly the response for the healthy state of plate is taken, with the application of force at a constant time. Piezoelectric patch was connected to DSO via cable to channel 1 and corresponding response was recorded. As the hammer strikes the plate, voltage response can be seen on DSO. The interference due to noise was minimized with the help of the amplifier. Signature for the voltage and frequency response of the PZT patch is obtained. Fig. 3, 4 shows voltage response and frequency response of the piezo-materials attached to the structure respectively. The plot in Fig. 3 shows the variation of voltage with respect to time and in the signature it is observed that initially the voltage is constant but increases suddenly as the hammer hits the plate.

The plot in Fig. 4 shows the FFT of the same voltage response which converts time domain data into frequency domain. All these responses are for healthy State of the plate specimen.

B. Response for Damaged State

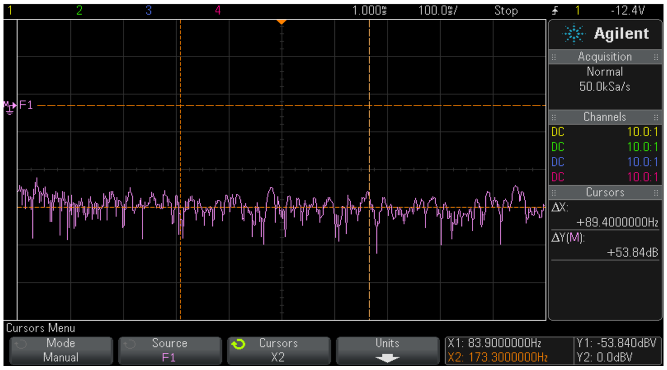
The test is carried out for all damaged states; Incipient state, Moderate state, Severe state. The response for each damaged state is found out in voltage vs. time and frequency plot as shown in Figures below for thin plate and thick plate respectively.

C. Response of thin plate



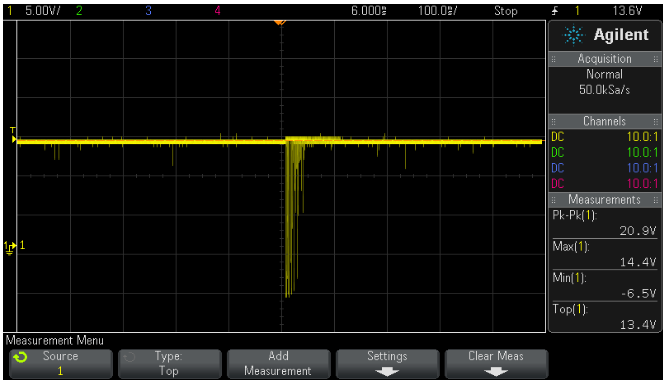
Pk-Pk(1): 21.7V
Max(1): 15.7V
Min(1): -6.0V
Top(1): 13.8V
Source 1
Type Absolute
Lower 800.0mV
Middle 1.200V
Upper 1.500V

Fig. 3 Voltage vs. time for Pristine State.



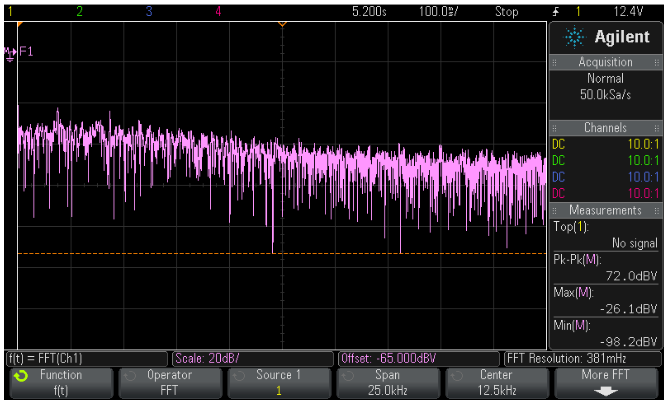
ΔX: +89.4000000Hz
ΔY(M): +53.84dB
Mode Manual
Source F1
Cursors X2
Units
X1: 83.9000000Hz
X2: 173.3000000Hz
Y1: -53.840dBV
Y2: 0.0dBV

Fig. 4 FFT for Pristine State



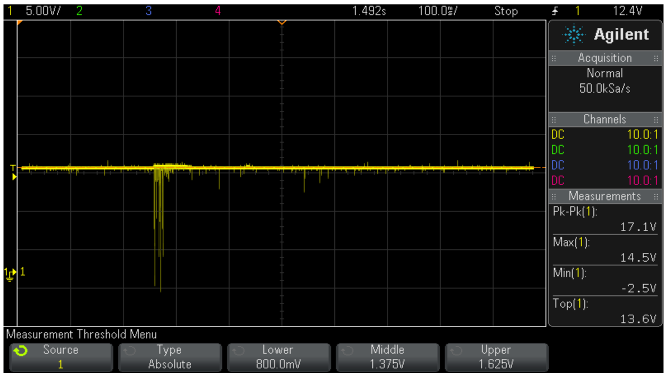
Pk-Pk(1): 20.9V
Max(1): 14.4V
Min(1): -6.5V
Top(1): 13.4V
Source 1
Type: Top

Fig. 5 Voltage vs. time for Incipient State



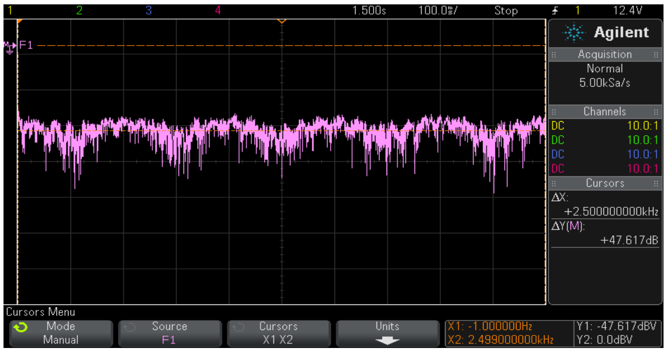
Top(1): No signal
Pk-Pk(M): 72.0dBV
Max(M): -26.1dBV
Min(M): -98.2dBV
f(t) = FFT(Ch1)
Scale: 20dB/
Offset: -65.000dBV
FFT Resolution: 381mHz
Function f(t)
Operator FFT
Source 1 1
Span 25.0kHz
Center 12.5kHz

Fig. 6 FFT for Incipient State



Pk-Pk(1): 17.1V
Max(1): 14.5V
Min(1): -2.5V
Top(1): 13.6V
Source 1
Type Absolute
Lower 800.0mV
Middle 1.375V
Upper 1.625V

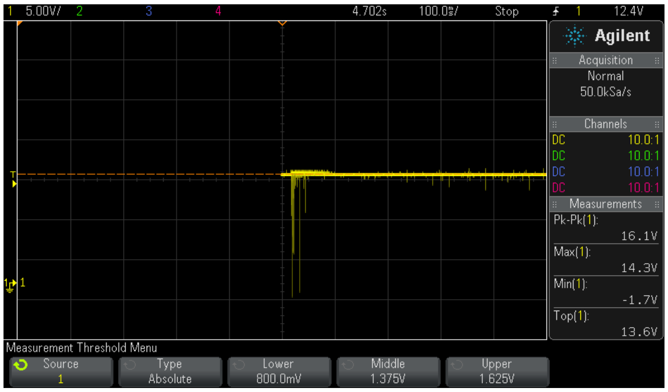
Fig. 7 Voltage vs. time for Moderate State



ΔX: +2.500000000kHz
ΔY(M): +47.617dB
Mode Manual
Source F1
Cursors X1 X2
Units
X1: -1.000000Hz
X2: 2.499000000kHz
Y1: -47.617dBV
Y2: 0.0dBV

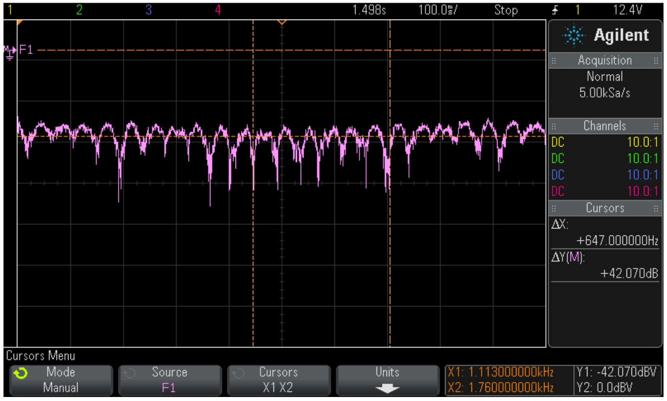
Fig. 8 FFT for Moderate State

D. Response of thick plate



Pk-Pk(1): 16.1V
Max(1): 14.3V
Min(1): -1.7V
Top(1): 13.6V
Source 1
Type Absolute
Lower 800.0mV
Middle 1.375V
Upper 1.625V

Fig. 9 Voltage vs. time for Severe State



ΔX: +647.000000Hz
ΔY(M): +42.070dB
Mode Manual
Source F1
Cursors X1 X2
Units
X1: 1.113000000kHz
X2: 1.760000000kHz
Y1: -42.070dBV
Y2: 0.0dBV

Fig. 10 FFT for Severe State

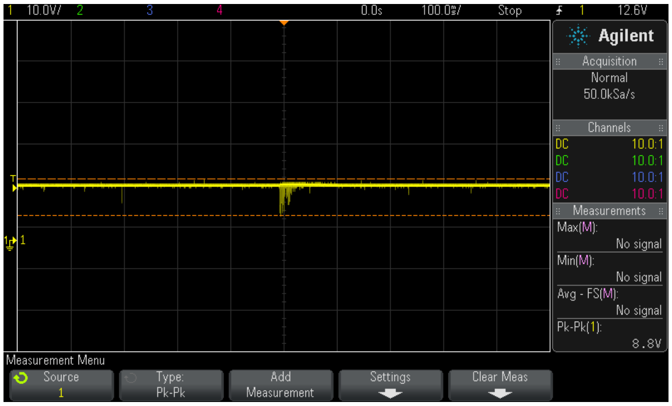


Fig. 11 Voltage vs. time for Pristine State.

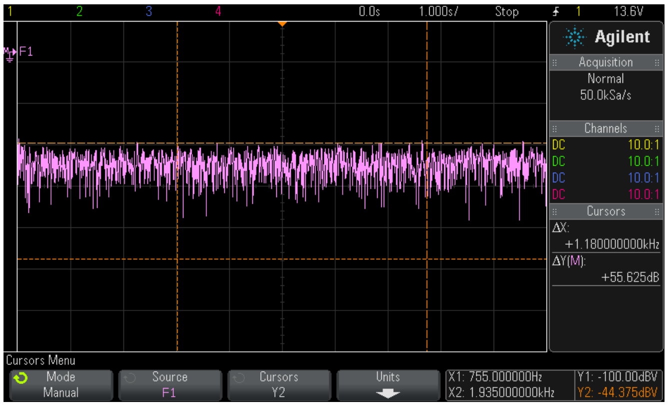


Fig. 12 FFT for Pristine State

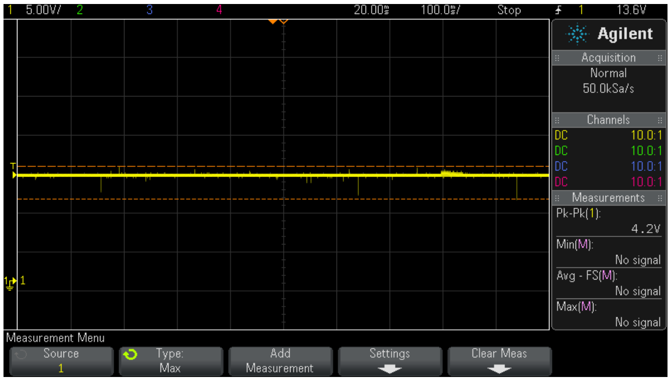


Fig. 13 Voltage vs. time for Incipient State

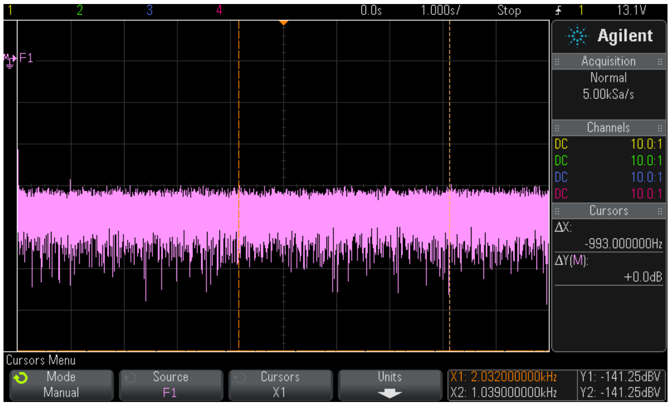


Fig. 14 FFT for Incipient State

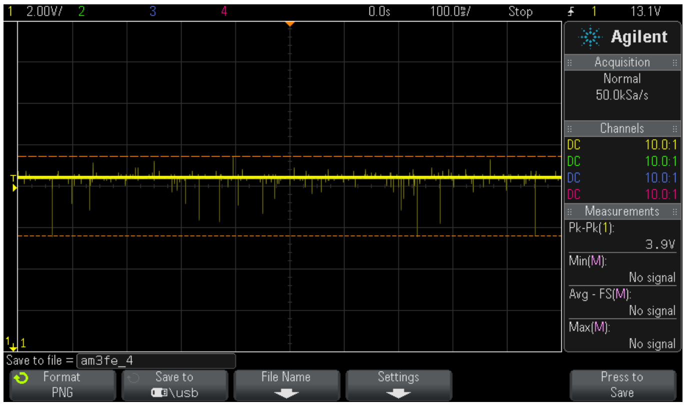


Fig. 15 Voltage vs. time for Moderate State

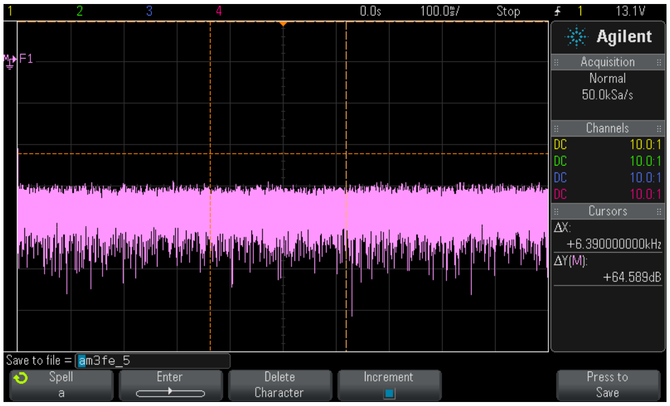


Fig. 16 FFT for Moderate State

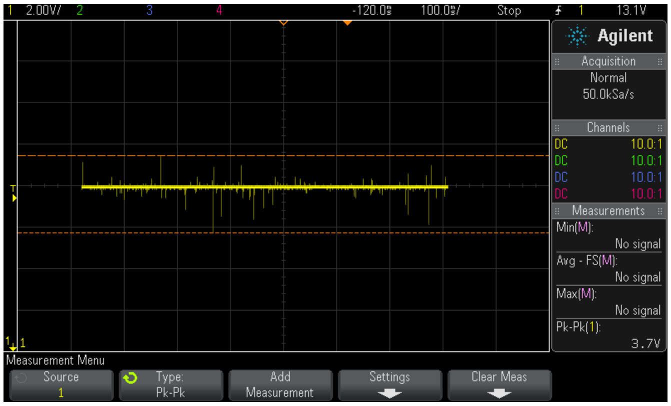


Fig. 17 Voltage vs. time for Severe State

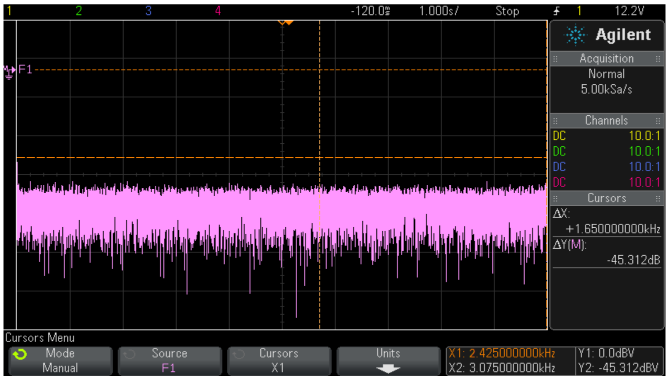


Fig. 18 FFT for Severe State

IV. CONCLUSION

From results obtained experimentally on a plate specimen for simply supported condition by using PZT patch, it is concluded that:

1. Piezoelectric materials hold potential in the fields of SHM and structural repair.
2. From the results, it is observed that the voltage versus time response goes on reducing as the damage is induced in each state. Hence, the stiffness of the plate reduces with the amount of damage induced.
3. Also the frequency domain of the plate increases from Hz to kHz with the increase in the state of damage. Hence, Vibration in the plate increases with the increase in amount of damage.
4. Piezoelectric materials have remarkable sensing and exciting capacities and detect cracks in reasonable accuracy.
5. In addition, as an alternative to conventional methods used for structural repair, the technique using piezoelectric materials is quick enough to enable appropriate remedial action and achieve a significant reduction in inspection time, effort and cost.

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