Journal of Civil Engineering and Environmental Technology
Print ISSN: 2349-8404; Online ISSN: 2349-879X; Volume 1, Number 6; August, 2014 pp. 41-45

http://www.krishisanskriti.org/jceet.html

Experimental Modeal Analysis of Structural Beam Using Piezoelectric Sensor

Siddharth Sharma[1], Sumedha Moharana[2]

[1]Undergraduate Student, Mechanical Engineering, Shiv Nadar University, Uttar Pradesh, India
siddharthsh-me15@snu.edu.in
[2]Assistant Professor, Civil Engineering, Shiv Nadar University, Uttar Pradesh, India
sumedha.maharana@snu.edu.in

Abstract: **Over past 30 years assessment of structural Damages has drawn attention of Civil, Mechanical and aerospace engineers and thus automated nature of seasoning system and continuous performance assessment is gaining importance and thus in modern world structural health monitoring is important. Piezoelectric sensors have been employed for the health monitoring of structures owing to their simultaneous sensing/actuating capability. This paper is aim to assess damages in one dimensional structure using curvature mode shape technique. Occurrence of damages are determined using frequency response function (damaged and undamaged) based on the global dynamic technique. Finally, damage severity was determined in terms of the curvature mode shapes directly obtained through response of piezoelectric sensor.**

1. INTRODUCTION

In the modern technological scenario, structural health monitoring (SHM) is one of the most researched topics. SHM is gaining importance day by day as failure of any infrastructure causes severe loss of life and economy. SHM can be described as the process of continuously monitoring the structure from the day of its construction to the end of its life period. Various methods are available to monitor the structure. The global dynamic techniques are used only in low frequency range (typically < 200Hz) and can detect moderate to severe damage (Akten., 1998[1]; Shanker et. al., 2011[2]). Curvature mode shape technique is a part of global vibration techniques. The primary objective of this work is to assess damage in one dimensional structure using curvature mode shape technique based on piezoceramic sensors.

A structural health monitoring (SHM) system comprises a distributed array of sensors, embedded inside or attached to a structure, along with the hardware to transmit and analyses the data from the sensors. The purpose of the system is to continuously or periodically monitor the integrity of the structure or detect any abnormal behavior and take remedial action. Over the long term, the output of the process is updated information about the ability of the structure to perform its intended function in light of aging and degradation from the environment. Although health monitoring is a maturing concept in the manufacturing, automotive and aerospace industries, there are a number of challenges for its effective applications on civil and defence infrastructure systems. While successful real-life studies on a new or an existing structure are critical for transforming health monitoring from research to practice, laboratory benchmark studies are also essential for addressing issues related to the main needs and challenges of structural health monitoring.

2. VIBRATION TECHNIQUES

The basic principle of vibration techniques is to apply structural excitations through actuators or other means, and to measure structural response through measurement of displacement, acceleration, strain or velocity. Changes in natural frequencies or mode shapes indicate changes in the structure, which in turn can indicate that damage has occurred. Existence of structural damage in an engineering system leads to modification of the vibration modes. These modes are manifested as changes in modal parameters such as the natural frequencies, the mode shapes and the modal damping values, which can be obtained from the results of dynamic vibration testing. Changes in modal parameters may not be the same for each mode since the changes depend on the nature, location and severity of the damage. This effect offers the possibility of using data from dynamic testing to detect, locate and quantify damage.

The advantage of measuring vibration responses is the global nature of the derived natural frequencies which allows measurement points to be chosen to suit the test situation. Modal parameters can be easily obtained from the measured vibration responses with relatively less effort. Conventionally, the responses are acquired by some type of transducer, generally accelerometers, which monitor the structural response to artificially induced excitation forces or ambient forces in the service environment. Low input energy levels are sufficient to produce measurable responses since the input energy is dynamically amplified.

Results from some experimental and numerical studies have suggested that the lower vibration modes are fully capable of damage detection. However, it is also well established that modes higher than first should be used in damage detection so as to improve the identification. The increased sensitivity of the higher modes to local damage has been reported by Alampalli et al. (1992)[3]. Since higher modes are usually unavailable from the results of a full-scale modal survey, their use in damage detection cannot be implemented in real practice through usual dynamic techniques.

During the recent years, PZT patches have been employed for the health monitoring of structures owing to their simultaneous sensing/actuating capability. The structural health monitoring has been gaining more importance in civil engineering areas such as wind engineering and earthquake engineering. However, only few structures such as historical buildings and few critical bridges have been instrumented with structural monitoring system due to high cost of installation, long and complicated system of wires and lack of knowledge about modern sensors.

This paper aimed at developing a generic system to apply global vibration technique in one dimensional structure subjected to damage using Lead Zirconate Titanate (PZT) sensors. PZT sensors are not only cost effective but also small, structure-compatible, durable and long lasting. In this paper the experiment is done on an aluminum beam (simply supported condition) specimen. The PZT sensors are coupled and bonded on surface of steel beam to obtain the curvature mode shapes of the beam (damaged and undamaged).

2.1 Global Vibration Techniques for SHM

The presence of damage or deterioration in a structure causes changes in the natural frequencies of the structure. The most useful damage location methods (based on dynamic testing) are probably those using changes in resonant frequencies because frequency measurements can be quickly conducted and are generally reliable. Abnormal loss of stiffness is inferred when measured natural frequencies are substantially lower than expected (Bhalla., 2001)[4].

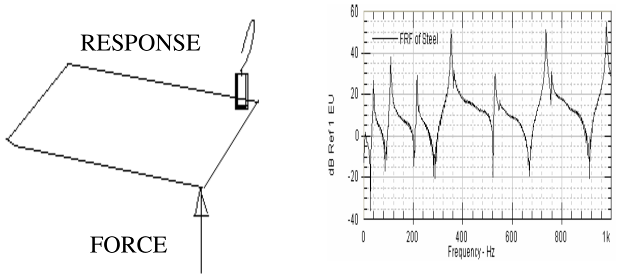
At nodal nodes (points of zero modal displacements), the stress is minimum for the particular mode of vibration. Hence, the minimal change in a particular modal frequency could mean that the defect may be close to the modal node. The other modal frequency variations can still be used to determine the magnitude of damage. When using vibration testing for integrity assessment and for successful utilization of vibration data in assessing structural condition, the measurements should be taken at certain specific points. The simplest way of achieving this is to conduct a theoretical vibration analysis of the structure prior to testing. The best positions would be those points where the sum of the magnitude of the mode shape vectors is maximized.

The advantage of measuring vibration responses is the global nature of the derived natural frequencies and this allows measurement points to be chosen to suit the test situation. The disadvantages associated with the global dynamic technique i.e. of lengthy flexible matrices and structural stiffness has been done away by this technique. Also PZT patches have been employed for the health monitoring of structures owing to their simultaneous sensing/actuating capability, and lower cost as compared to the accelerometers. Modal parameters can be easily obtained from the measured vibration responses with relatively less effort and can be acquired by any commercial data acquisition system.

2.2. Modal Analysis

Modal analysis is a process whereby we describe a structure in terms of its natural characteristics namely the frequency, damping and mode shapes-its dynamic properties.

Let's consider a freely supported flat plate (Figure.1. (a)). Let us consider a fixed frequency of the constant force. We will change the rate of oscillation of the frequency but the peak force will always be the same value-only the rate of oscillation of the force will change. We will also measure the response of the plate due to the excitation with an accelerometer attached to one of the plate.



a) Plate b) Frequency response function (FRF)

Fig. 1 Simple plate excitation/response model (Avitable, 2008)[6]

Now if we measure the response on the plate, we will notice that the amplitude changes as we change the rate of oscillation of the input force (Figure.1. (b)). There will be increase as well decrease in amplitude at different points as we sweep up in time. This is exactly what happens –the response amplifies as we apply with a rate of oscillation that gets closer and closer to the natural frequency (or resonant frequency) of the system and reaches a maximum when the rate of oscillation is at the resonant frequency of the system.

This time data provides very useful information. But if we take the time data and transform it to the frequency domain using Fast Fourier Transform (FFT) then we can compute something called the frequency response function (FRF).Now, if we overlay the time trace with the frequency trace what we will notice is that the frequency of oscillation at the time at which the time trace reaches its maximum value corresponds to the frequency where peaks in the frequency response function reaches a maximum. So we can use either the time trace to determine the frequency at which maximum amplitude increases occur or the frequency response function to determine where these natural frequencies occur. Clearly, the frequency response function is easier to evaluate.

The modal analysis has the following advantages:

(a) It can assist in the design of almost any structure.

(b) It can help to identify areas of weakness in the design or areas where improvement is needed.

(c) Uses modal data to determine the effects of changes in the system characteristics due to structural changes.

(d) A very important aspect of modal testing is that it can be correlated and corrected with the analytical or numerical model of the structure.

3. PIEZOELECTRIC MATERIALS AS DYNAMIC STRAIN SENSOR

The phenomenon of piezoelectricity occurs in certain classes of non-cento-symmetric crystals, such as quartz, in which electric dipoles (and hence surface charges) are generated due to mechanical deformations. The same crystals also exhibit the converse effect; that is, they undergo mechanical deformations when subjected to electric fields. The constitutive relations for piezoelectric materials for 1D interaction (Bhalla, 2004)[5], such as for a piezoelectric plate are shown in Equation (1) and (2).

$$D_3 = \in_{33}^{T} E_3 + d_{31} T_1 \quad (1)$$

$$S_1 = \frac{T_1}{Y^E} + d_{31} E_3 \quad (2)$$

where, d_{31} is Piezoelectric strain coefficient, S_1 is strain, D_3 is Electric charge density over PZT, Y^E is Young's modulus of the PZT patch at zero eclectic fields, $\in_{33}^{T}$ is Complex permittivity of the PZT at zero stress and E_3 is Electric field in direction 3. If a PZT patch surface bonded on a structure is desired to be used as a sensor only (with no external electric field across its terminals, i.e. $E_3 = 0$, its governing sensing Equation (2) can be reduced to Shankar et al., (2011)[2].

$$D_3 = d_{31} Y^E S_1 \quad (3)$$

where $Y^E S_1$ has been substituted for T_1 making use of the Hooke's law. From the theory of parallel place capacitors, the charge density can also be expressed as

$$D_3 = \frac{\in_{33}^{T} V}{h} \quad (4)$$

where V is the potential difference across the terminals of the PZT patch of thickness h. Using Equations (2) and (3), the strain in the PZT patch (and hence on the structure it is bonded to) can be expressed in terms of the voltage measured across its terminals as

$$S_1 = \left(\frac{\in_{33}^{T}}{d_{31} h Y^E} \right) V = K_p V \quad (5)$$

A Simply supported beam is chosen for the experiment as Curvature mode shape and displacement mode shapes are of same form and changes in the curvature mode shapes increases with the increase in the damage and hence amount of damage in the structure can be obtained.

4. EXPERIMENTAL PROCEDURE

The experiment is done on an aluminum beam (see figure.2b.) bonded with the PZT sensor under simply supported condition. It is divided into four equal parts such that each part is a nodes depicted in the figure 2 and PZT sensor is in the middle.

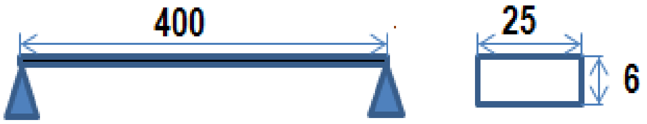


Fig. 2a. Simply supported beam mode (all dimensions in mm)

Fig. 2b. Actual experimental Aluminium strip

In this experiment force is applied at all four nodes as represented in the Figure.3. and output is obtained using PZT in Digital oscilloscope.

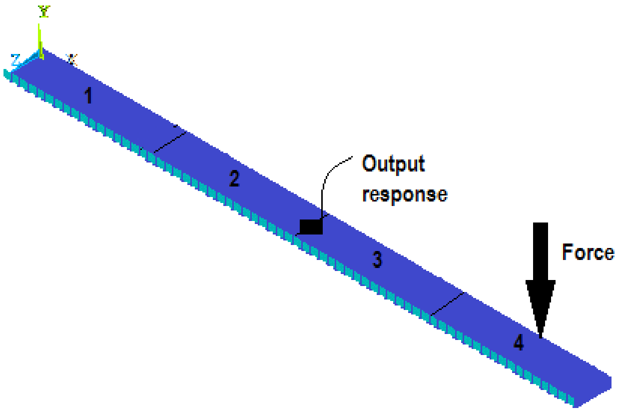


Fig. 3. Simple Plate excitation model

Output is obtained for both impact hammer and beam. The output is obtained in the time domain and it is converted into frequency domain by doing Fast Fourier Transformation This transformation gives complex values comprising of real and imaginary part. The frequency response function (FRF) can be calculated as

$$h(w) = \frac{\mu}{F} \tag{6}$$

Experiment is done for damaged beam i.e. adding some additional mass in beam at two different locations. Natural Frequency of undamaged beam is at 28 Hz. In this method one PZT sensor was used to take response and impact was done at seven different locations.

One channel of oscilloscope was connected to PZT sensor and other channel was connected to force measuring device force sensor. FRF of each response and force was obtained by using MATLAB® program. Peak point at natural frequency at every node location was used to plot curvature mode shape.

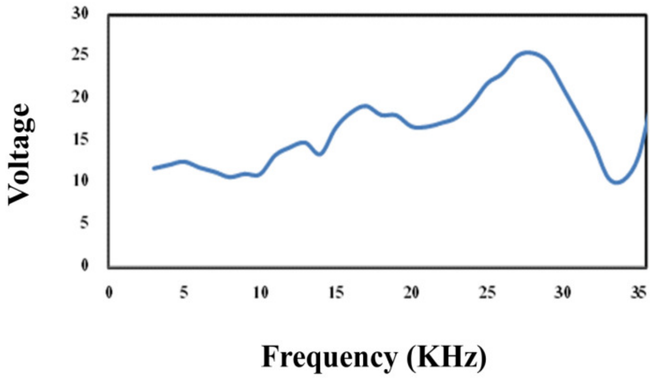


Fig. 4. Natural Frequency of aluminum Beam for undamaged condition

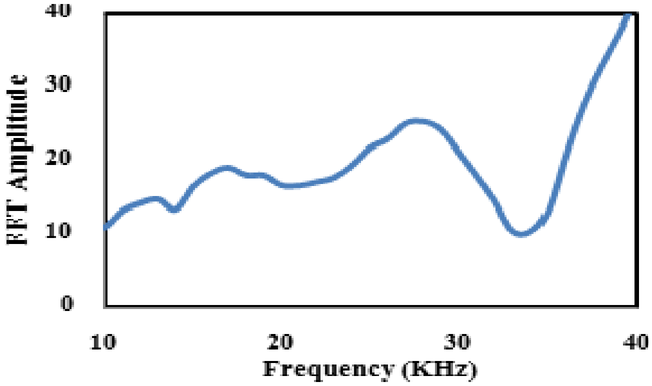


Fig. 5. Natural Frequency of aluminum Beam for damaged condition

To detect damage in specimen the comparison is done between the sensor responses for different node position where the excitation was given through force hammer. The following figures represent the piezo response for input force excitation in different node location of beam for both undamaged and damaged condition.

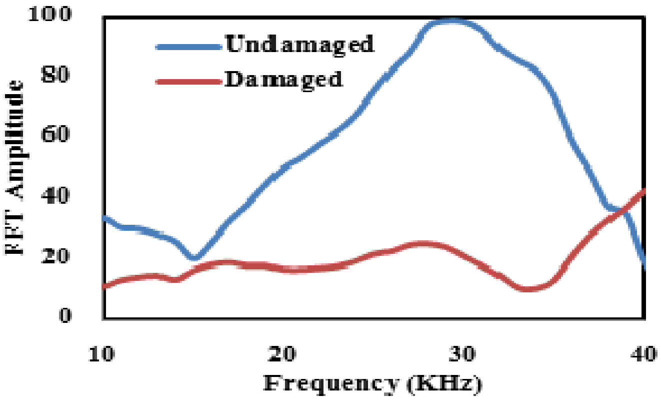


Fig. 6. Frequency response of sensor for force at node1

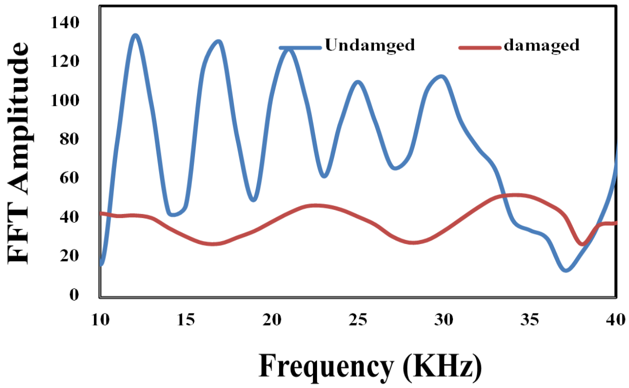


Fig. 7. Frequency response of sensor for force at node2

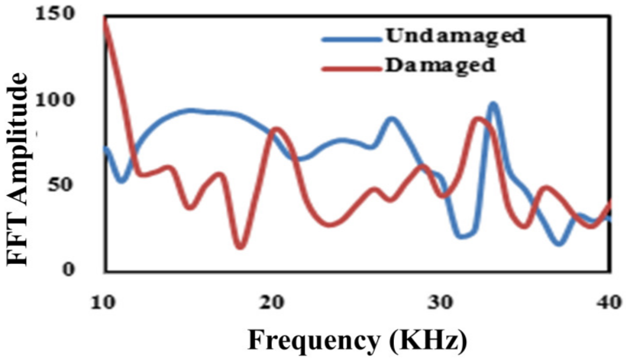


Fig. 8. Frequency response of sensor for force at node3

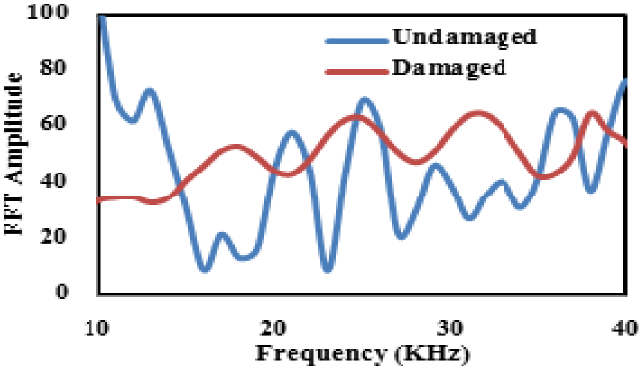


Fig. 9. Frequency response of sensor for force at node4

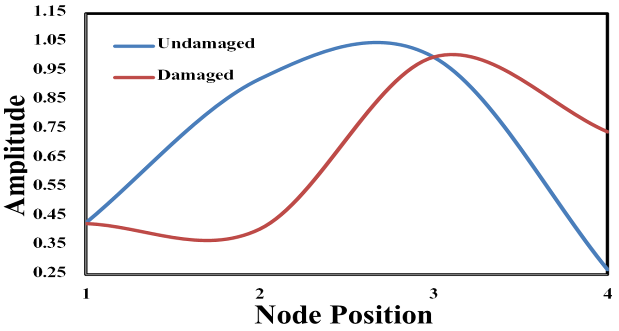


Fig. 10. Mode Shape of aluminum beam identified by piezo response for both damaged and undamaged condition

The mode shape is obtained by using frequency response function of piezo sensor. The Comparison of mode shape is done to localize the damage position in beam. Figure.10. represents the mode shape of beam for both damaged and undamaged condition. The variation in mode shape is significant at node position 2 and 3, where artificial damage is induced be adding mass in that location. Figure.10. represents the quantification of damage severity for the beam. The damage severity of beam can be evaluated by subtracting peak amplitude of Relative difference in peak values of undamaged and damaged beam.

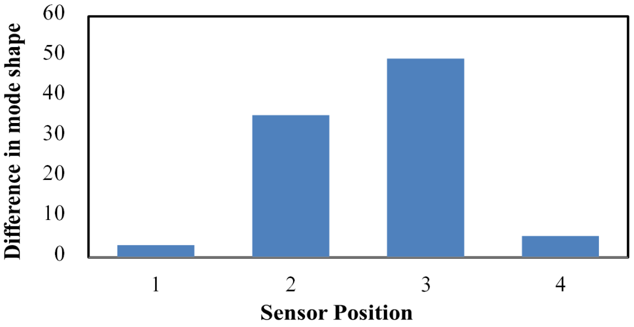


Fig. 11. Relative difference in peak values of undamaged and damaged beam

5. CONCLUSION

This paper is aimed to assess damage in one dimensional structure using curvature mode shape technique based on global vibration technique, operates on low frequency range (typically < 200Hz). The experiment has been done on an aluminum beam bonded with the PZT sensor under simply supported condition. Occurrence of the damage is determined using frequency response function (damaged and undamaged). Finally, damage severity was determined in terms of the experimental mode shapes directly obtained through response of piezoelectric sensor. It is found to be an efficient, cost effective technique for detecting damage in complex civil, mechanical and aerospace structures as it is free of complex analytical model and save time from large computational effort.

REFERENCES

[1] Aktan, A. E., Helmicki, A J. and Hunt, V. J., "Issues In Health Monitoring For Intelligent Infrastructure", *Smart Materials and Structures*, Vol. 7, No. 5, pp. 674-692, (1998).

[2] Shanker, Rama, et al. "Dual use of PZT patches as sensors in global dynamic and local electromechanical impedance techniques for structural health monitoring." *Journal of Intelligent Material Systems and Structures* (2011).

[3] Alampalli, S., Fu, G. and Aziz L.A., "Modal Analysis as a Bridge Inspection Tool", *Proceedings of the 10th international modal analysis conference (IMAC),* San Diego, 1359-1366, (1992)

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

[5] Bhalla, S., "A Mechanical Impedance Approach for Structural Identification, Health Monitoring and Non-Destructive Evaluation using Piezo-Impedance Transducers", *PhD Thesis, Nanyang Technological University, Singapore,* (2004).

[6] Avitable, P., University of Massachusetts Lowell, USA,, "A Simple Non-Mathematical Presentation on Modal Analysis and Controls Laboratory Mechanical Engg".(2008)