Non Destructive Evaluation and Structural Health Monitoring: A Review

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Abstract— Structural health monitoring has great potential for enhancing the functionality, serviceability and increased life span of structures. Structural health monitoring is defined as "continuous, autonomous, real time, in-service monitoring of the physical condition of a structure by means of embedded or attached sensors with minimum manual intervention". This need which arises from the fact that intensive usage combined with long endurance causes gradual but unnoticed deterioration in structures, often leading to unexpected disasters. Recently smart piezoelectric-ceramic lead material is emerged as high frequency impedance transducers for non-destructive evaluation. In this role, the PZT patches act as collocated actuators and sensors and employ ultrasonic vibrations gives a characteristic admittance 'signature' of the structure. The admittance signature has vital information about the nature of the structure, and it can be analysed to predict the onset of structural damages. PZT patches exhibit excellent performance as far as damage sensitivity. Their sensitivity is high enough to capture any structural damage at the incipient stage. There are different Non-Destructive techniques like acoustic emission, ultrasonic, acousto-ultrasonic, guided ultrasonic waves or Lamb waves. The Lamb wavebased active SHM method uses piezoelectric (PZT) sensors to transmit and receive wave. Thus, Lamb waves generated by PZT sensors and time-frequency analysis techniques could be used effectively for damage detection. This study has given a complete idea of the working and the basic requirements of SHM system.

Key words: Structural Health Monitoring (SHM), Nondestructive Evaluation (NDE), PZT Patches, Lamb Waves

I. INTRODUCTION

Structural health monitoring provides the ability of a system to detect adverse changes within a system's structure. SHM is an emerging technology that has multiple applications. Development of new techniques for structural health monitoring (SHM) and non-destructive evaluation (NDE) is need arises from the fact that intensive usage combined with long endurance causes gradual but unnoticed deterioration in structures, often leading to unexpected disasters. In this PZT materials, for example, have recently emerged as high frequency impedance transducers for SHM and NDE. In this role, the PZT patches act as collocated actuators and sensors and employ ultrasonic vibrations gives a characteristic admittance 'signature' of the structure. With the increasing number of civil structures, it has become a necessity to monitor these structures regularly via Non-destructive Testing/ Structural Health Monitoring methods, to prevent catastrophic failures. Also it is required to implement cost-effective measures and ease of implementation. This way the cost gets reduced as it minimizes maintenance and inspection cycles.

II. REVIEW OF LITERATURE

A. *Nishanth R. and Maheshprabhu.R, et.all [1]*

Has carried out study on structural health monitoring which is based on Lamb wave propagation. It has been developed especially for distinguishing different kinds of damages. The Lamb wave-based active SHM method uses piezoelectric (PZT) sensors to transmit and receive Lamb waves in a thin Aluminium plate. The Lamb wave modes travel into the structure and are reflected by the structural boundaries, discontinuities, and damage. By studying their propagation and reflection, the presence of defect in the structure is determined. Laboratory level experiments have been carried out on thin Aluminium plates with angular, horizontal and vertical defect. This study provides significant insight into the problem of identifying localized damages in the structure using PZT and dispersion of signal after they interact with different types of damage. Those small defect like the horizontal one that may be nearly missed in time domain analysis can also be clearly identified in the STFT analysis. Moreover the occurrence of so mode is also clearly seen. Thus, Lamb waves generated by PZT sensors and time-frequency analysis techniques could be used effectively for damage detection in aluminium plate.

B. *Hui-Ru Shih, Wilbur L. Walters et. all [2]*

Has carried out study on structural health monitoring (SHM) is an emerging technology that has multiple applications. SHM emerged from the wide field of smart structures, and it also encompasses disciplines such as structural dynamics, materials and structures, non-destructive testing, sensors and actuators, data acquisition, signal processing, and possibly much more.

C. *Dr. Suresh Bhalla and Chee-Kiong Soh [3]*

has carried out study on development of new techniques for structural health monitoring (SHM) and non-destructive evaluation (NDE) is need arises from the fact that intensive usage combined with long endurance causes gradual but unnoticed deterioration in structures, often leading to unexpected disasters. In this smart piezoelectric-ceramic lead zirconate titanate (PZT) materials, for example, have recently emerged as high frequency impedance transducers for SHM and NDE. In this role, the PZT patches act as collocated actuators and sensors and employ ultrasonic vibrations (typically in 30-400 kHz range) to glean out a characteristic admittance 'signature' of the structure. The admittance signature encompasses vital information governing the phenomenological nature of the structure, and can be analysed to predict the onset of structural damages. As impedance transducers, the PZT patches exhibit excellent performance as far as damage sensitivity and cost-effectiveness are concerned. Typically, their sensitivity is high enough to capture any structural damage at the incipient stage, well before it acquires detectable macroscopic dimensions. This new SHM/ NDE technique is popularly called the electro-mechanical impedance (EMI) technique in the literature.

D. Dr. Suresh Bhalla and Faizal [4]

has carried out study on condition assessment of the structures by using low frequency technique is done through experimental modal analysis and computational analysis software ANSYS 9.0 over structural elements beam and steel frame. In the Experimental Modal Analysis, investigation is carried over a 2m and 4m Reinforced concrete beam and rectangular hollow section steel frame. In the computational Analysis using ANSYS 9.0 the Modal Analysis is done both in the one dimensional and three dimensional modelling. Damage induced analysis is carried in the ANSYS 9.0 and the difference in the modal frequency is noted, which was compared in the experimental modal analysis of the damage induced analysis of the beam. Damage detection and Condition assessment of the beams were carried out with Mode shape curvature and Flexibility method, changes in the beam element were compared with the real time experimental specimen and damage detection was found in very close approximation.

E. Shih-Lin Hung and C. Y. Kao [5]

Has carried out study on a novel neural network-based approach to detect structural damage. The proposed approach comprises two steps. The first step, system identification, involves using neural system identification networks (NSINs) to identify the undamaged and damaged states of a structural system. The partial derivatives of the outputs with respect to the inputs of the NSIN, which identifies the system in a certain undamaged or damaged state. This loosely defined unique property enables these partial derivatives to quantitatively indicate system damage from the model parameters. The second step, structural damage detection, involves using the neural damage detection network (NDDN) to detect the location and extent of the structural damage.

F. L. Skarbek, T. Wandowski et. all [6]

Has carried out study on the impedance method which was used to diagnose the structural state of isotropic beam. The piezoelectric elements were bonded to the surface of the host structure and supplied by alternating low voltage source. Different measurement cases were investigated using various configurations of power supply to piezoelectric transducers such as different or the same polarization applied to transducers bonded on the opposite sides of the beam. Piezoelectric transducers were supplied from the same source, so they also affected each other. Transducers used in experiment are a CeramTec SONOX P502 piezoelectric transducers. The electromechanical impedance method is widely used in high frequency range. It can be treated as modal analysis for high frequencies (up to MHz), because the impedance is directly related to frequency response function of the system.

G. Cristian Rugina, Adrian Toader et. all[7]

Has carried out work on the electro-mechanical (E/M) impedance method which applied to structural health monitoring (SHM) of thin circular plates. The method allows to identify the local dynamics of the structure directly through the E/M impedance signatures of piezoelectric wafer active sensors (PWAS) permanently mounted to the structure. An analytical model for 2-D thin-wall structures, which predicts the E/M impedance response at PWAS terminals, was developed and validated. The model accounts for axial and flexural vibrations of the structure and considers both the structural dynamics and the sensor dynamics. Comparisons between the analytical method, the finite element method, and experiments were performed, with a fabricated structural arc-shape defect.

H. Victor Giurgiutiu and Craig A. Rogers[8]

Has carried out investigation on the electro-mechanical impedance method. A further examination of the complex interaction between wave propagation, drive-point impedance, structural damage and electro-mechanical impedance of the piezo-electric wafer transducer is needed. Once these aspects are better understood, the E/M impedance method has the potential to become a widely used NDE technique with large applicability in diverse engineering fields.

I. Fabricio G. Baptista , Danilo E. Budoya, et.all [9]

Has carried out work on the effect of temperature on the electrical impedance of the piezoelectric sensors used in the EMI technique. They used 5H PZT (lead zirconate titanate) ceramic sensors, which are commonly used in the EMI technique. The experimental results showed that the temperature effects were strongly frequency-dependent, which may motivate future research in the SHM field.

J. Saurab Verma, Annamdas Venu Gopal Madhav et. all[10]

Has carried out work on gradual changes in the properties of concrete during the curing process of 30 days. For the purpose, a 150 x 150 x 150 mm3 cubic concrete block was subjected to the test. Signatures were obtained using embedded and surface-bonded piezoelectric transducers (PZTs). The EM (admittance) signatures were processed using statistical indices like RMSD, for different periods of frequencies. But the conventional statistical tools did not serve the purpose in this situation. Hence, a new technique was devised (called RDSD) later. Results from surface-bonded PZT were also compared to those from embedded PZT patch and based-on conclusions were deduced.

III. Summary

This paper described the recent developments in structural health monitoring and non-destructive evaluation using surface bonded piezo-impedance transducers. The approach presented here can be very useful in the development of a continuous structural health or condition monitoring system because of its simplicity and can be extended into an automated system with minimal requirement for operator involvement. This ability should result in major reductions in the cost of sustaining current and future advanced structures, extend the service life of aging aircraft fleet, and provide new capabilities for improving structural safety and reliability. Practical implementation of the technique in real structures will, however, require additional research involving laboratory tests.

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