Structural Health Monitoring: The Process of Implementing a Damage Detection

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Abstract- ***Materials are evolving today at a rate faster than any other time in the history of civilization. The emergence of new and improved materials, their processing and the development of a newer area of specialization known as Materials Design are stimulating innovation in all the walks of life making new designs for efficient systems and structures. Structural health monitoring (SHM) refers to the process of implementing a damage detection and characterization strategy for engineering structures. The smart materials possess the ability to change their physical properties in a specific manner in response to specific stimulus input on real time basis. They are light in weight, consume less power and have better reliability. In addition, they can be embedded in the structures without affecting the structural properties. With such features incorporated in a structure by embedding functional materials, it is feasible to achieve technological advances such as vibration and noise reduction, shape control with high pointing accuracy, damage detection, damage mitigation etc.***

Index Terms- Monitoring, sensors, piezoelectric, optical fiber, acoustics

I. INTRODUCTION

Composites are fast gaining attention as structural materials due to overriding advantages over conventional metallic structures. Owing to their high specific strength and stiffness and very good corrosion and fatigue properties, they are increasingly being used in the design of light weight aerospace, automobile and civil structures. Further, there is an increasing application of advanced composites in varied fields such as marine structures, turbine blades, automobile bodies etc. This increase in usage of composites has raised the necessity for evaluating the in-service performance of such structures. All structures, including critical civil infrastructure facilities like bridges and highways, deteriorate with time due to various reasons including fatigue failure caused by repetitive traffic loads, effects of environmental conditions, and extreme events such as an earthquake. This requires not just routine or critical-event based inspections (such as an earthquake), but rather a means of continuous monitoring of a structure to provide an assessment of changes as a function of time and an early warning of an unsafe condition using real-time data. Thus, the health monitoring of structures has been a hot research topic of structural engineering in recent years. First, this work highlights the structural damage detection methods as a step of structural health monitoring (SHM) via discussing the differences between global and local damage detection techniques and the merits of each technique. Furthermore, it presents the interpretation of the localization of the derivatives of response-based damage detection methods. Next, the state of the art of different global damage detection methods and their applications are presented. Thus, vibration-based methods, static response-based method, physical model-based method, as well as implementation of long-term SHM to critical civil structures are discussed. Finally, the state of the art and the future of different types of response measurements and their applications in SHM of civil structures are reviewed. Also, some advances in measurement responses; such as laser doppler vibrometer (LDV) and fiber optic sensors (FOSs) are illustrated. Identify.

II. STRUCRURAL HEALTH MONITORING TECHNIQUES

Structural health monitoring (SHM) relies on sensors that can be permanently placed on the structure and monitored over time either in a passive or in an active way. These sensors should be affordable, lightweight, and unobtrusive such as to not impose cost and weight penalty on the structure and to not interfere with the structural strength and airworthiness. Some of the sensor types that have been considered for SHM applications are:

1) Conventional resistance strain gauges
2) Fiber optic sensors, e.g., fiber Bragg gratings (FBG) strain sensors
3) Piezoelectric wafer active sensors (PWAS)
4) Electrical properties sensors: - resistance, impedance, dielectric, etc.

These sensors may operate in static and dynamic regimes, depending on the physical principle that is employed in monitoring the structure. Other damage measuring methods based on large area measurements (ultrasonic C-scans, scanning Doppler laser velocimetry, thermography, etc.) have been used in SHM development for definition and confirmation of damage and/or for understating the proposed SHM approach

III. SHM & SMART MATERIALS

One of the foremost drives for the implementation of SHM is due to the feasibility of augmenting smart and functional materials in host structures which can act as sensors / actuators to present the state of the affairs of a structure on continuous basis.

A. Smart Material

Materials which possess the ability to change their physical properties in a specific manner in response to specific stimulus input are called smart materials

B. Smart System or structure

A system or a material which has built in or intrinsic sensor(s), actuator(s) and control mechanism whereby it is capable of sensing a stimulus, responding to it in a predetermined manner and extent in a short / appropriate time and reverting to its original state as soon as the stimulus is removed.

C. Smart System or structure

Smart materials can be termed as active or passive. Active materials possess the capacity to modify their material and geometric properties under application of electrical, thermal or magnetic field and thereby acquiring an inherent capacity to transduce energy. Piezoelectric materials, shape memory alloys, electro-rheological fluids and magneto strictive materials are important active smart materials and they may be used as sensors and actuators. Passive smart materials do not have the inherent capability to transduce energy. Fiber optic materials are good examples of passive smart material. They are mainly used for sensing purposes.

IV. SMART MATERIALS: FUTURE APPLICATION SCENARIO

Following advancements could be possible in the field of smart materials and structures:

1) Materials which can restrain the propagation of cracks by automatically producing compressive stresses around them to arrest the damage (damage arrest).

2) Materials which can discriminate whether the loading is static or impact type and can generate a large force against shock stresses (shock absorbers).

3) Materials possessing self-repairing capabilities which can heal the damages in due course of time (self-healing materials).

4) Materials which are useable up to ultra-high temperatures such as those encountered by space shuttles when they reenter the atmosphere of earth from outer space by suitably changing composition through transformation (thermal mitigation).

V. EMERGING SHM TECHNOLOGIES

The very basis of SHM is its ability to monitor structures using embedded / attached sensors and to utilize the data to assess the state of the structure. Non-destructive evaluation sensors for SHM purposes have attained a modest degree of maturity and are able to monitor significantly large areas of structures. Following are the important SHM technologies:

1) Piezoelectric sensors
2) Magnetostrictive sensors
3) Optical fiber sensors
4) Dynamic response analysis using Laser Doppler Vibrometer

Piezoelectric sensors convert mechanical energy into electrical energy and vice versa. This phenomenon enables them to detect impacts and deformations in a structure. Lead Zirconate Titanate (PZT) is the most commonly used piezoelectric material. It is used in the form of patches. Since it is a hard ceramic which is weak in tension it is not always possible to embed it into a structure. The most common piezo-polymer for sensing dynamic strain is PVDF. PVDF sensors are not likely to modify the stiffness of the host structure due to their own low stiffness. Being a polymer PVDF film can be shaped as desired according to intended application and can be formed into very thin films making it attractive for sensing purposes.

Acoustic emission (AE) is elastic radiation generated by the rapid release of energy from inside the material. These elastic waves are detected and converted to electrical signals by piezoelectric transducers bonded to the material surface. Fracture, impact, corrosive film rupture and other similar deformation processes may cause acoustic emission. Acoustic emission is fairly sensitive to detect newly formed crack surfaces of micron level. AE is a proven and reliable structural health monitoring tool for predictive maintenance and detects the cracks and damages well before they may endanger the well-being of the structure.

Acousto-ultrasonics uses pulser and receivers with resonant frequencies in low ultrasonic range to detect damages. Ultrasonic waves are reflected by surfaces and interfaces, attenuated by dispersion and absorption and undergo mode changes during reflection and transmission. The technique is able to detect and characterize differences in the structure of single and multilayer metallic and composite structures. When damage has occurred to a structure, changes in the signal indicate the type of damage.

In EMI technique, a PZT actuator/sensor patch is bonded to the surface of the structure whose health is monitored using high strength epoxy adhesive. The conductance signature of the patch is obtained over a high frequency range. This signature is the benchmark for assessing the health of a structure. The signature of the bonded PZT patch is acquired using impedance analyzer. Electro-mechanical coupling between mechanical impedance Z of the host structure and electro-mechanical admittance Y is utilized in damage detection. Z is a function of the structural parameters such as stiffness, damping and the mass distribution. Any damage to the structure will lead to change in these structural parameters, hence, the mechanical impedance. Cracks, debonding and damage in connections are the common causes that alter the structural impedance.

VI. CONCLUSION

Following are the envisaged benefits of SHM system:

1) Replacing schedule-based inspection / maintenance of the structure to condition based maintenance brings great cost reduction.
2) Extends the life of over aging structures.
3) Attempts to identify damage in structures on a more global basis.
4) Opens avenues for possible integration of the design of the structure with its full management as a part of still bigger system.
5) Conventionally, surface bonded PZT patches are used to monitor the health of structures. There are several difficulties like protection from harsh environment and external wiring associated with the surface bonded PZT patches. In this research, possibility of an embedded PZT sensor has been investigated which can be embedded in structure at the time of construction. It is successfully demonstrated that the embedded sensor acts well in both the global dynamic technique and the EMI technique. Simple low cost digital multi-meter is used to measure the response of the embedded sensor.

ACKNOWLEDGMENT

There is a phenomenal rise in construction activities in the field of civil engineering in the recent years. Major structures like buildings, bridges, dams are subjected to severe loading and their performance is likely to change with time. It is, therefore, necessary to check the performance of a structure through continuous monitoring. If performance deviates from the design parameters, appropriate maintenance is required. The life of a structure depends on initial strength and the post construction maintenance. It is for this reason that

the necessity of structural health monitoring (SHM) is emphasized worldwide. There are several techniques to monitor the health of structures. These can be divided broadly into two types, global and local. The local and global techniques independently cannot monitor the health of a structure continuously in an autonomous manner. For example, the global technique, cannot determine incipient damage. The local techniques, being localized in nature, can identify damage only within a limited zone. Hence, a technique is required for structural health monitoring (SHM), which should carry out continuous monitoring of structure both locally and globally, should be sensitive and at the same time cost effective. The primary objective of this research work is to develop a new technique by integrating the global and local techniques based on piezoceramic sensors.

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