PIZOECLECTRIC CONCEPTS OF SMART MATERIALS FOR STRUCTURAL HEALTH MONITORING

Abstruct:- Smart materials are those materials which have the capability to change their physical properties such as the shape, stiffness, viscosity, etc. in a specific manner under specific stimulus. Smart materials are the basic components of smart structures. The piezoelectric materials and optical fibers are the examples of smart material. Smart structures have ability to sense change in their environment, optimally adjust themselves, and take appropriate action. A system can be considered as 'smart' if it is able of recognize an external stimulus and respond to it in a predetermined way in a given time interval. Besides it is expected to have the capability of identifying its status and may optimally adapt its function to external stimuli or give appropriate signal to the user. Smart structures have the capability to monitor their own condition, detect impending failure, control, or heal damage and adapt to changing environment. A smart system typically comprises of the two components: Sensors and Actuators and works on the concept of piezoelectricity. Piezoelectric materials are smart materials because they generate a surface charge in response to applied mechanical stress. Conversely, they undergo a material deformation in response to an applied electric field.

Keywords:- Smart Material, Actuator, Sensor, PZT Patch,

1-INTRODUCTION:

The piezoelectric effect was discovered in 1880 by Jacques and Pierre Curie. It occurs in certain crystalline minerals, which when subjected to a mechanical force, become electrically polarized. Tension and compression produce voltages of opposite polarity that is proportional to the applied forces. This is called the direct effect. The converse effect was discovered by Lippman in 1881 in which the crystal was exposed to an electric field, under which it stretched or shortened according to the polarity of the electric field and in proportion to the strength of the field. A smart system must have a mechanism for integrating the sensors and actuators. . A smart system typically comprises of the following components:

1.1*Sensors*

A smart system must gather information about its surroundings before taking the appropriate action. This work is carried out by sensors. Sensors recognize and measure the intensity of the stimulus (stress or strain) or its effect on the structure. They gather the information about the ambient environment and finally transfer information to the actuators for suitable action.Examples of smart sensors are optical fiber sensors, piezo films, pizoceramic patches etc.

1.2*Actuators*

A smart system may additionally have embedded or bonded actuators, which is responsive to stimulus in a predetermined manner.

1.3*Control Mechanism*

A smart structure must have a mechanism from intersection of sensor and actuator. Sensors and actuators are required to be integrated in feedback system for controlling the states of the structural system.

2-PIEZOELECTRICITY

The piezoelectric effect was discovered in 1880 by Jacques and Pierre Curie. It occurs in certain crystalline minerals, which when subjected to a mechanical force, become electrically polarized. Tension and compression produce voltages of opposite polarity that is proportional to the applied forces. This is called the direct effect. The converse effect was discovered by Lippman in 1881 in which the crystal was exposed to an electric field, under which it stretched or shortened according to the polarity of the electric field and in proportion to the strength of the field. A smart system must have a mechanism for integrating the sensors and actuators. Piezoelectric materials are smart materials because they generate a surface charge in response to applied mechanical stress. Conversely, they undergo a material deformation in response to an applied electric field. This unique capabilities enables the smart material to be used as a sensor and an actuator.

Beginning with 20th century, development of metal oxide-based piezoelectric ceramics and other synthetic materials encouraged engineers to apply the direct and converse piezoelectric effects in novel applications. These materials are generally having enough stiffness and chemically inactive, and inexpensive to manufacture. The composition and geometry of a piezoelectric ceramic can be customized as per the application requirement. Ceramics manufactured from integration of lead zirconate/lead titanate show more sensitivity and higher operating temperatures in comparison to the ceramics of other compositions. "PZT" material (lead zirconate titanate) is currently the most widely used piezoelectric ceramic.

3-GEOMETRIC DETAILS OF PZT PATCHES

There are several types of PZT patches commercially available in market in different geometries (circular, rectangular and square)as well as in thickness. Electrodes position varies from patch to patch. Electrodes are situated on opposite side in some PZT patches whereas in others the electrode from the bottom edge is wrapped around the thickness, so that both electrodes are available on one side of the PZT patch, facilitating when the other side to be bonded to the host structure. In EMI technique, PZT patches of sizes ranging from 5 mm to 15 mm and thickness from

0.1 to 0.3 are best suited for most structural materials such as steel and reinforced concrete. Such thin patches usually have thickness resonance frequency of the order of few MHz (Bhalla, 2004). A typical PZT patch manufactured by PI Ceramic (2009) is shown in Fig. 2.1.

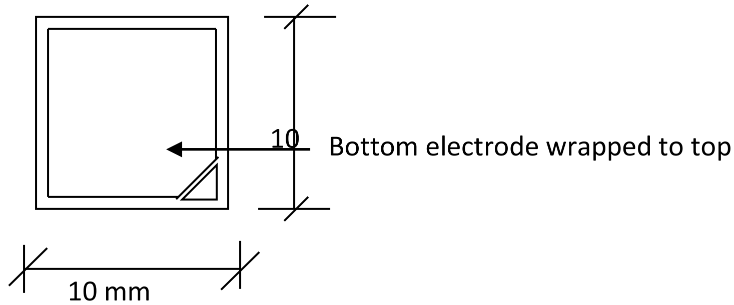

Figure2.1: Detail of PZT patch

4-APPLICATIONS OF PIZOELECTRIC MATERIALS:-

Since this thesis is primarily focused towards the application of piezoelectric materials, some typical applications of these materials are briefly described here. Traditionally, piezoelectric materials have been well-known for their use in accelerometers, strain sensors (Sirohi and Chopra, 2000b), emitters and receptors of stress waves (Giurgiutiu et al., 2000b; Boller, 2002), distributed vibration sensors (Choi and Chang, 1996; Kawiecki, 1998), actuators (Sirohi and Chopra, 2000a) and pressure transducers (Zhu, 2003). However, since last decade, the piezoelectric materials, their derivative devices and structures have been increasingly employed in turbo-machinery actuators, vibration dampers and active vibration control of stationary/ moving structures e.g. helicopter blades (Chopra, 2000). They are successfully used in active structural control of lab-sized structures and machines (Manning et al., 2000; Song et al., 2002). Structural control of large structures has also been implemented (Kamada et al., 1997). Other new applications include underwater acoustic absorption, robotics, precision positioning and smart skins for submarines (Kumar, 1991). Skin-like tactile sensors utilizing piezoelectric effect for sensing temperatures and pressures have been reported (Rogers, 1990). Very recently, the piezoelectric materials have been employed to produce micro and nano scale systems and wireless inter digital transducers (IDT) using advanced embedded system technologies, which are set to find numerous applications in micro-electronics, bio-medical and SHM (Varadan, 2002; Lynch et al., 2003b). Recent research is also exploring the development of versatile piezo-fibres, which can be integrated with composite structures for actuation and SHM (Boller, 2002).

The most striking application of the piezoelectric materials in SHM has been in the form of EMI technique. Applications of the piezoelectric materials in global dynamic techniques are explored in this thesis. In brief, piezo-ceramic patches namely PZT wafers have substantial applications as sensors, actuators, electric generators and ultrasonic transducers.

5-PROBLEMS IN APPLICATION OF PIEZOELECTRIC MATERIAL FOR STRUCTURAL HEALTH MONITORING

Piezoelectric ceramic elements are used to monitor the health of structures via EMI technique since mid-nineties. Damage detection is based on comparison of signature with benchmark signature. Ideally, the change in signature should be due to deterioration of health of structure only and not from any other reason. However, it is possible that signature of PZT can change due to other reasons such as:

5.1 *Aging*

PZT patches erode gradually, with time after polarization as logarithmic function (PI Ceramic, 2009). Rates of degradation of PZT patches depend on manufacturing processand chemical composition of the ceramic element. Degradation of PZT patches possibly stimulate changes in the reference signature.

5.2 *Electrical Limitations*

PZT patches depolarizes if it is exposed to a strong electric field of polarity opposite to that of the polarizing field. The magnetic field between 200 to 500 V/mm or greater typically has a significant depolarizing effect. The degree of depolarization depends upon the propertyof the material, the temperature, the exposure timeand other factors. An alternating current will have a depolarizing effect during which polarity is opposite to the polarizing field for each half cycle.

5.3 *Mechanical Limitations*

Application of mechanical stress on piezoelectric material beyond certain limit can damage the alignment of dipole. This limit depends upon the type of grade and the brand of the material used to prepare the PZT patches.

5.4 *Thermal Limitations and Temperature Fluctuations*

If a piezoelectric ceramic material is heated above the Curie temperature the domains become disordered and the material gets depolarized. The recommended operating temperature for a ceramic is usually between 0°C and the Curie point. Orientations of the domains are reversible within the recommended operating temperature range. In the other words, these changes can create displacement sand electric fields. High voltages induced in ceramic elements are capable to depolarize them due to abrupt temperature variations. A capacitor may be integrated into the system to accept the redundant electrical energy. Temperature fluctuations affect the properties of PZT patch such as $d_{31}, \overline{\varepsilon_{33}^{T}}, \text{and } \overline{Y^{E}}$ and to some extent structural properties of the host system. Hence, temperature fluctuations result in horizontal/vertical shift in the signature.

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