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Active Vibration Control Structures Using Piezoelectric Materials: A Review

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Abstract -

The purpose of this study is to focus on the application of piezoelectric material to control the vibration of the structures. Piezoceramics are low cost, light weight and easy to implement materials which can be applied to minimize the amplitude of structural vibration. The basic principle of piezoelectric actuation is also discussed in this study. Piezoceramics are applied as sensor or actuators or in both form of sensor and actuators by different authors. It is available in various forms such as rigid patch, flexible patch, stack etc.In this study an attempt has been taken to discuss the application of various form of piezoceramics for active control of structural vibration.

Keywords: piezoelectric material, actuators, cantilever beams, excitation frequencies,Active vibration control

I. INTRODUCTION

Numerous attempts have been made to reduce the unwanted vibration in structures as vibration may cause damage to a structure or degradation of a system's performance.Such reduction of vibration can be accomplished by using either active or passive methods.Active methods need an actuator. Piezoelectric materials are used in active damping as well as in passive damping or shut damping. In this study, a review is presented for vibration control of structures using piezoelectric materials where only active vibration control techniques have been considered for discussion.Two types of piezoelectric bender actuators are piezoelectric bimorph and piezoelectric unimorph.

Piezoelectric Bimorph

It consists of two thin layer of piezoelectric elements bonded to each other.The bimorph can be used in two configurations (a) series and (b) parallel

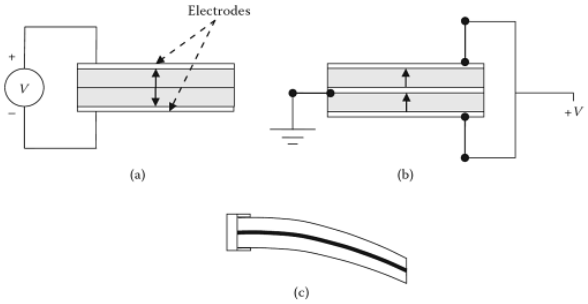

Figure 1

Figure.1 Piezoelectric Bimorph Beam: (a) Series configuration: Voltage is applied across the two outer electrode (b) Parallel configuration: The two strips are poled in the same direction and the voltage applied between the electrodes (c) Bimorph in the bend form

Piezoelectric Unimorph

It is a cantilever consists of a single strip of piezoelectric material clamped at one end and free at the other end.The bending of cantilever on application of voltage is used for actuation.It is made of thin film of piezoelectric material formed on a non piezoelectric substrate material.The voltage is applied across the piezoelectric film due to which it gets strained,the substrate material resists the strain and results in bending of unimorph.

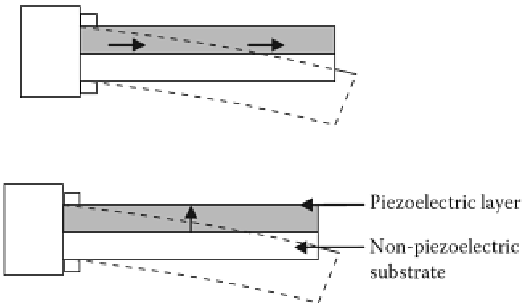

Figure 2: Piezoelectric Unimorph

Bending Mechanism

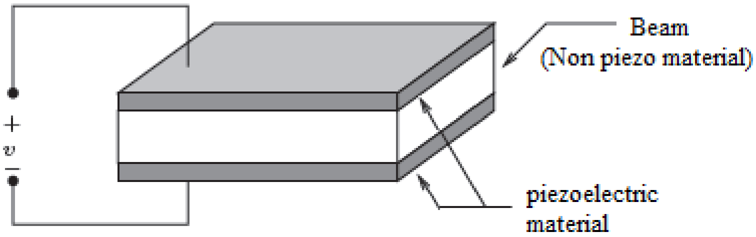

Figure 3

The figure 4 shows the upper and lower piezoelectric elements bonded on the beam surface,the lower element having its polarization parallel to electricfield and the upper is antiparallel to it.On application of electric fields the upper element expands simultaneously the lower one contracts leads to the bending in downward direction.This is done by applying equalvoltages, of 180° phase difference, to the two patches. Due to the phase difference between the voltages applied to the two actuators, only pure bending of the beam will occur, without any excitation of longitudinal waves.In this way the upward movement of the cantilever beam due to the external excitation can be controlled. In the similar manner during the downward movement of the beam due to external excitation an upward bending of the piezoelectric patch will try to control the amplitude of the vibration [1]

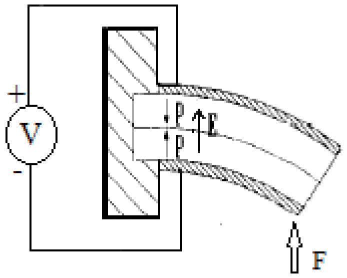

Figure 4

The Linear Piezoelectric Equations

A piezoelectric ceramic is a ferroelectric material. It exhibits hysteresis andhas nonlinear behavior. When this material is poled (placed in a strong electric field), it attains a permanently polarized state. For a small variationin the electric field, it behaves approximately linearly near that state.The linear piezoelectric equations are written in two different forms. Inthe more common form, which is called the strain form, the strain tensor εijand the electric polarization vector *Pi* are each written as linear functions ofthe electric field vector *Ei* and the stress tensor *σij* . These equations are [2]

$$\varepsilon_{ij}= E_k d_{kij}+ c_{ijkl}\sigma_{kl} \qquad (1)$$

$$P_i = \epsilon_0\chi_{ij} E_j + d_{ijk}\sigma_{jk} \; (2)$$

The $d_{ijk}$are the components of the piezoelectric tensor (strain coefficients).The $c_{ijkl}$are the components of the inverse elastic tensor. The constant $\epsilon_0$is the permittivity of free space. The $\chi_{ij}$are the components of the electric susceptibility tensor. In the direct piezoelectric effect,when a piezoelectricmaterial is put under a stress, the material becomes electrically polarized and surface charges appear. Direct piezoelectric effect is

$$Pi = d_{ijk}\sigma_{jk},(3)$$

which is obtained from the second equation, when the external electric field is zero.

II. LITERATURE REVIEW

As the piezoelectric materials have the ability to generate electrical charge in proportion to an externally applied force and an electric field parallel to the directionof polarization induces an expansion of the piezoelectric material, therefore many researchers motivated to work in the field of smart structure.The smart structure can be defined as the structure that can sense external disturbance and respond to that with active control in real time to maintain the mission requirements. Therefore a smart structure has four major components: the structure, sensor, actuator and controller. Piezo actuators and sensors are widely used in various applications and are integrated with the main structure via surface bonding or embedding.

Bailey and Hubbar (1985) [3] initiated the research on the application of the smart structures in active vibration control.

Baz and Poh (1988) [4] controlled the vibration of flexible beams by the piezoelectric actuators. A modified independent modal space control method was presented to select the optimal location, control gains and excitation voltage of the piezoelectric actuators. The piezoelectric actuator was bonded to the flexible beam to form a composite beam. The elongation or compression of the piezoelectric material relative to the beam by virtue of the piezoelectric effect created longitudinal bending stresses in the composite beam in a manner very similar to a bimetallic thermostat which in turn counterbalanced the effect of the exciting forces and moments acting on the beam to attenuate vibration.

Gaudenzi et al. (2000) [5] controlled the vibration of the active cantilever beam by means of position and velocity control. The sensing and actuating actions had been carried out by two identical PZT piezo-patches attached to the lower and upper side of the cantilever beam.

Balamurugan and Narayanan (2001) [6] presented an active vibration control method of beam like structures with distributed piezoelectric sensor and actuator layers bonded on top and bottom surfaces of the beam. Direct proportional feedback, constant-gain negative velocity feedback and Lyapunov feedback and an optimal control strategy, linear quadratic regulator (LQR) scheme were applied to study their control effectiveness. They also studied the control performance of the actuator with different types of loading, such as impulse, step, harmonic and random.

The development of finite element codes, such as ANSYSTM, makes it possible to fully model coupled thermo mechanical-electrical systems of one or more dimensions and obtain reciprocal relationsbetween piezoelectric actuator voltages and system response. Ansys software was used by Yaman et al.(2001) [7] to control the vibration of an aluminum cantilever smart beam with surface bonded piezoelectric (PZT) patches. They used Ansys (v5.6) to generate the finite element model of the cantilever beam and piezoelectric patches. In this study, that smart beam was modeled by considering twoapproaches. In the first approach the solid elements (SOLID5) were used for themodeling of the active portion (piezoelectric patches) and compatible solid elements(SOLID45) were used for the modeling of the passive portion (aluminum beam). Thisis called as ‘hybrid solid-solid model’. Then the passive structure was modeled with shellelements (SHELL99) whereas the piezoelectric patches were still solid elements.This second model was denoted as ‘hybrid shell-solid model’. The specimen was thentheoretically subjected to a piezoelectric actuation voltage of 400V. Using this finite element model they designed an H_∞ controller which effectively suppressed the vibration of the smart beam for the first two modes.

Kermani et al. (2002) [8] provided practical guidelines that should be useful for selecting optimized locations, geometrical dimensions and parameters of a PZT actuator for exerting a moment on a flexible beam to minimize the vibration.

Melin et al (2006) [9] shows the application of smart materials in the vibration control of aeronautical structures by obtaining the analytical and numerical models of aluminum beam-like and plate-like structureswith the help of sets of data used to verify and improve the theoreticallydeveloped control models for smart beams. Further the work was carried out with NATO/RTO/AVT Panel project T-129. The main vision of the project was development of control strategies by using control techniques with PZTs inactive vibration control of smart structures and their experimental verification

G.E. Stavroulakis et al (2005) [10] presented the mathematical formulation and designed a vibration control mechanism using H_2 and LQR for a beam with piezoelectric sensor and actuators. The mechanical model of structure was based on the classical engineering theory of bending the finite element method was used to developed beam structure along with Hamilton’s principle .The vibration control performance was measured with LQR controller to established the robustness with respect to external disturbance.

M. Rios-Gutierrezet.al [11] shows the mechanical vibration absorption of a cantilever beam by an active controlscheme. The experimental set up had an aluminum cantilever beam attachedto electro dynamical shaker. It has a piezoelectric patch as a main actuator and the feedback signal is sensed with a small piezoelectric accelerometer. A positivefeedback controller is attached for control purposes of the closed loop.Four element finite model is considered for the modeling of beam. The complicated systems such as flexible robots rotating machinery, smart structuresare ideal for the implementation of vibrationsuppression using piezoelectric patch.

Z.K. Kusculuoglu et.al. (2004) [12] used the Piezoceramic wafer (patch) actuatorsfor investigation of excitation and control the vibrations of beam and plate-like structures. Apiezoelectric patch actuator with finite element model of a beam was presented.Timoshenko beam theory has been used for modeling of thebeam and the patch actuator as well. For surety of the continuity of the transverse and axial displacements at the interface of the Timoshenko elements theconstraints were introduced. This setup allows the individual rotation of each cross section leads to the high accuracy as compared to conventional formulation.The factored matrix formdisplacementfield is presentedwhich helps to derive the stiffnessmatrices and element mass. The measure of experimental and theoretical frequency responsefunctions of beam system and pizopatch are acquired withthe piezopatch electrically closed and open circuited. The element model includes dielectric behavior of the piezoceramic wafer

Jens Becker et.al. (2006) [13] presented the reduction of structural vibrations by connecting the shunted piezoelectric patches with passive electrical network. This approach stabilized the system with less complicity in implementation and generally called as shunt piezo damping.finite element methodology has been formulated for piezoelectric coupling of patches and dynamics of electrical circuit. The damping ratio is obtained by the eigen value problem corresponding to the coupled model. Since local stiffening and mass effects are included in the model it gives accurate prediction of natural frequency and dampind ratio as well. The paper shows the experimental study of the impact parameters of passive electrical network.

Frank Goldschmidtboeing and Peter Woias (2008) [14] studied various beam shape for piezoelectric energy harvester based on the theory of Rayleigh-Ritz method for piezoelectric compound structures. They found that triangular shaped beams are more effective than rectangular ones in terms of tolerable excitation with negligible overall efficiency influenced by the beam shape. The dependence of maximum tolerable excitation amplitude on the shape of the beam has been clearly shown in this paper.

C.M.A. Vasques et.al (2006) [15] produced an analytical comparison between classical control strategies and optimal control strategies concerned with respect to active vibration control of smart piezoelectric beams. A cantilever beam made up of aluminum was analyzed along with asymmetric pair of piezoelectric patches mounted on its surface. The measurement of few quantities like transverse displacement time history, white noise force disturbance and driving point receptance was done at the free end of the beam for efficient comparison of classical and optimal strategies under frequency and time domain.

III. CONCLUSION

The vibration control of beam is considered as an important engineering problem because it will enhance the stability of the system. In this paper a review is conducted on the active vibration control method of beam using smart material. As piezoelectric materials are low cost, light weight and easy to implement materials therefore many authors attempted to control the vibration of structures using piezoelectric smart materials. They studied the behavior of piezoelectric materials under the influence of externally applied forces and electric current as well. Different methods of active vibration control using piezoelectric patches are discussed in this paper. Introduction of analytical software package (Ansys) is also discussed here for the modeling of smart beam structure. This survey will give an introduction to a new researcher in this field to different published papers at a single glance.

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