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Vibration Control by Piezoelectric Materials: A Review

[1]Thorat P.A.* [2] Londhe B.C. [3] Sonawane T.B.,
[1,3] M.E. student , [2] Associate Prof. Mechanical Engg. Dept., S.N.D. COE & RC Yeola, Dist.- Nasik, India.
(puja.thorat15@gmail.com) (babasaheb.londhe@rediffmail.com) (sonawane.yuram@gmail.com)

Abstract- ***The aim of this review paper is to represent a general study on the vibration control by piezoelectric materials. A piezoelectric material possesses the property of piezoelectricity, which describes the phenomenon of generating an electric charge in a material when subjected to a mechanical stress (direct effect) and, conversely, generating a mechanical strain in response to an applied electric field. This property prepares piezoceramic materials to be able to function as both sensors and actuators. The advantages of piezoceramic materials include high efficiency, no moving parts, fast response and being compact. Piezoelectric components can dampen vibrations particularly in the lower frequency range, either actively or passively.***

Keywords: ***vibration control, piezoelectric material, Piezo effect, PZT, control mount etc.***

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1. INTRODUCTION:

Piezoelectric elements, most notably Lead Zirconate Titanate (PZT), attenuate vibration by transferring energy between the mechanical and electrical domains of the material. A voltage develops across the electrodes when the material deforms and conversely, the elements strain when a voltage is applied across their electrodes. In passive vibration control applications, the piezoelectric elements are attached to a vibrating structure, and as they deform, energy is dissipated as current is driven through a shunt connected to its electrodes. The electrical components that comprise the shunt directly impact the current output, and thus energy dissipation, of the piezoelectric control techniques. The spatial configuration of the elements plays an important role in the efficacy of the piezoelectric vibration control techniques. An accurate modal analysis of the structure is required a priori to ensure that the elements are attached away from the nodal lines of a particular mode of interest and positioned in regions that maximize their modal controllability. Placement in these regions maximizes the electromechanical coupling between the elements and the vibrating structure, thereby increasing the efficiency of the techniques. These areas are well known for simple structures like beams and plates. However, for more complex systems, it can be difficult to precisely model the structural dynamics of such systems and to completely capture the environmental effects that influence the system's response over time. In addition, since the elements typically are bonded to the surface of the structure using epoxy, it is costly and difficult to reconfigure the elements should a change be required, or if the elements become damaged.*[1]*

Fig. 1 piezoelectric products

Piezoelectric Effect occurs naturally in quartz crystals, but can be induced in other materials, such as specially formulated ceramics consisting mainly of Lead, Zirconium, and Titanium (PZT). Because they are ceramics (piezoceramics) shown in fig.1, they can be formed to most any shape or size. In order to "activate" the piezo properties of the mix of metals, the material is first heated to its Curie temperature. There, a voltage field of a sufficient strength is applied in the desired direction, forcing the ions to realign along this polling axis. When the ceramic cools, the ions remember this polling and act accordingly.*[2]*

2. Literature Review:

A piezoceramic material possesses the property of piezoelectricity, which described the phenomenon of generating an electric charge in a material when subjected to a mechanical stress (direct effect) and, conversely, generating a mechanical strain in response to an applied electric field.

G Song, **J Vlattas**, **S E Johnson** and **B N Agrawal (2007)** In this literature described the analysis on 'Active vibration control of a space truss using a lead zirconate titanate stack actuator'. This paper presents design, implementation and experimental results of active vibration control of Naval Postgraduate School (NPS) space truss using a piezoelectric ceramic stack actuator.

To reduce the vibrations caused by the proof mass actuator, an active strut member is installed along a diagonal of the base bay of the truss. The active strut element consists of a piezoelectric ceramic actuator stack, a force transducer and mechanical interfaces. An integral plus double-integral force controller is designed to suppress vibration of the truss.[1]

Shiyu Zhou and Jianjun Shi (2007). This is an extensive literature review where survey focused on 'Active Balancing and Vibration Control of Rotating Machinery: A Survey.' Vibration suppression of rotating machinery is an important engineering problem. In this paper, a review of the research work performed in real-time active balancing and active vibration control for rotating machinery, as well as the research work on dynamic modeling and analysis techniques of rotor systems, is presented. The basic methodology and a brief assessment of major difficulties and future research needs are also provided .[2]

James B. Min Kirsten P. Duffy, August 2012 has studied the 'Piezoelectric Vibration Damping Study for Rotating Composite Fan Blades.' Resonant vibrations of aircraft engine blades cause blade fatigue problems in engines, which can lead to thicker and aerodynamically lower performing blade designs, increasing engine weight, fuel burn, and maintenance costs. In order to mitigate undesirable blade vibration levels, active piezoelectric vibration control has been investigated, potentially enabling thinner blade designs for higher performing blades and minimizing blade fatigue problems. While the piezoelectric damping idea has been investigated by other researchers over the years, very little study has been done including rotational effects.[3]

Levent Malgaca May, 2007 This described the analysis work on 'Integration of Active Vibration Control Methods With Finite Element Models Of Smart Structure'. Active control methods can be used to eliminate undesired vibrations in engineering structures. Using piezoelectric smart structures for the active vibration control has great potential in engineering applications. In this thesis, numerical and experimental studies on active vibration control of mechanical systems and smart structures have been presented [4].

Kaixiang LI, sept 2011 This shows the work on '. Structural vibration damping with synchronized energy transfer between piezoelectric patches' Synchronized Switch Damping with Energy Transfer (SSDET) was proposed in this document. This method damped the vibration by using the energy from other vibrating form. The objectives of the work reported in this document were threefold. This is consisted of introduction of SSDET principle and developing its control law. This part aimed at establishing the mathematical model and verifying the proposed method by mathematical tools. Then, the experiment validations were carried out.[5]

J.C. Collinger This described worked on "An investigation Into Using Magnetically Attached Piezoelectric Elements For Vibration Control". This analysis shows that the control mounts attenuate significant vibration of the steel beam. In this permanaent magnets are used to replace the traditional epoxy bond is demonstrated.

3. Vibration Control By PZT:

If the mechanical system is knocked off balance , this can result in vibrations which adversely affect plants, machines and sensitive devices and thus affect the quality of the products. In many applications it is not possible to wait until environmental influences dampen the vibration and bring it to a halt; moreover, several interferences usually overlap in time, resulting in a quite confusing vibration spectrum with a variety of frequencies.

The vibrations must therefore be insulated in order to dynamically decouple the object from it's surroundings and thus reduce the transmission of shocks and solid borne sound. Piezoelectric components can dampen vibrations particularly in the lower frequency range, either actively or passively.

3.1 Control of Structural Noise and Vibrations with Smart Materials:

Structural controls have recently been used to reduce acoustic radiation from vibrating structures, also referred to as structure-borne noise. Almost all of the studies have involved the implementation of an active control system. Sun *et al.* used piezoelectric actuators to reduce the structural vibrations and interior noise of a uniform cylindrical shell that models a fuselage section. Two distributed piezoelectric actuators were developed based upon the understanding of structural-acoustic coupling properties of the system. They applied a patch of active piezoelectric damping composites to the center of a 29.8-cm square plate made of thin aluminum. *[4]*

3.2 Vehicle Vibration and Noise Control :

Lecce *et al.* demonstrated vibration active control in a vehicle by using piezoelectric sensors and actuators. The active structural acoustic control was developed by integrating piezoceramic materials as sensors and actuators into some structural elements of the car. By controlling the vibrations, the structure-borne noise was reduced. A simple feed forward control system was implemented to control the floor panel vibrations indicated in fig.2. *[5]*

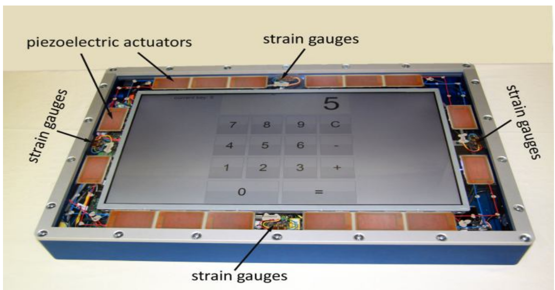

Fig.2 piezoelectric actuator with control system.

3.3 Magnetic-Piezoelectric Control Mount For Steel Beam:

In this the magnetic-piezoelectric control mounts, comprised of piezoelectric elements bonded to magnets, are attached to a steel beam through their magnetic attraction to control the response of the beam. The equations of motion for such a system are developed using a Hamiltonian analysis that incorporates the relative axial and lateral motion between the beam and the mounts. The axial and lat- eral displacements of the beam and the control mounts are deter- mined through a Galerkin finite element model.

Fig. 3 & Fig.4 shows the experimental set-up used in this work. *[8]*

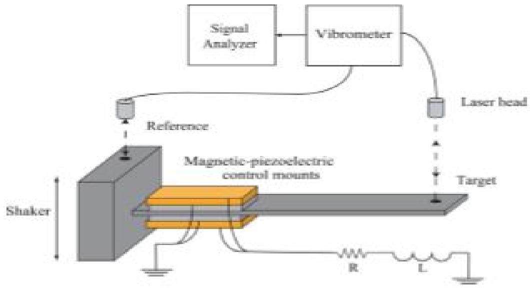

Fig. 3 Schematic block diagram of experimental set-up.

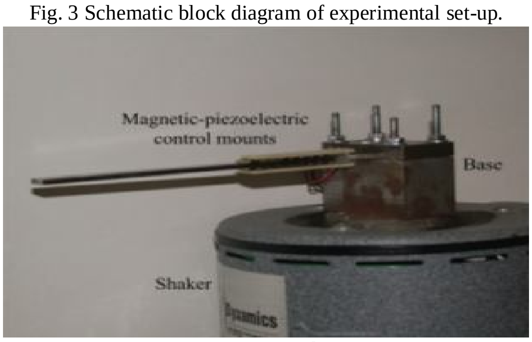

Fig.4 Experimental Set-up

3.3.1 Results :

The numerical model described in this section was applied to simulate the behavior of the beam with magnetically mounted piezoelectric elements. The electrodes were set to an open circuit condition. With each control mount having approximately the same mass, the natural frequencies of the system were largely influenced by the vertical and tangential contact stiffness's between the control mounts and the beam.

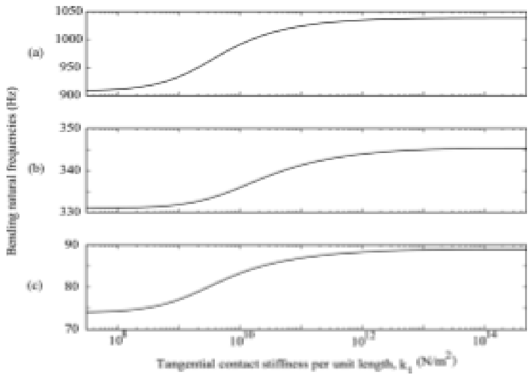

Fig.5 Illustration of the three bending natural frequencies for different contact stiffness.

Above Fig.5 illustrates the manner in which the first three natural frequencies varied for $k_v = 1x\ 10^{14}\ N/m^2$ and for various values of tangential contact stiffness, with the control mounts placed at location l= 0.32 cm. The torsional stiffness in the model was adjusted such that the simulated natural frequencies of the beam only (no mounts), which were 59 Hz(-1.6%), 362 Hz(1.1%) and 1017 Hz (0.1%), approximated the measured values with the percent error shown. For low contact stiffness ($k_t = 10^8$N/m2), the mounts had minimal influence on the bending natural frequencies, but as the stiffness was increased, the frequencies asymptotically approached those of a beam with perfectly bonded control mounts.

3.3.2 Experimental Results Comparison:

The magnetic- piezoelectric control mounts attenuated vibration even without perfect bonding. The measured and simulated tip velocity responses for the three different control mounts with no control and with resonant shunt control are shown in Fig.6 for two different sets of stiffness values.

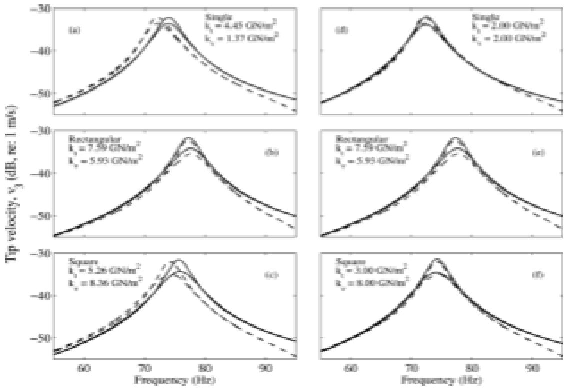

Fig.6 Simulated (solid) and measured(dashed) Tip velocity with and without resonant shunt control.

The magnetic- piezoelectric control mount's ability to attenuate vibration is de- pendent upon the strength of the magnetic bond between the beam and the control mounts. This is also an important parameter in determining whether the contact interface is sticking or slipping. A pulley assembly was designed to directly measure the slip force fs_1 between the different control mounts and the beam. Compared to the single magnetic block, slip occurred for the rectangular and square magnet configurations for slip forces 8 and 12:5 times larger, respectively as shown in Table 1.

Table:1 Comparison of the control mount's simulated normal force & measured slip force.

Control mount configuration	ANSYS simulation: Normal force (N)	ANSYS simulation: Ratio	Measured: Slip force, f_{sl} (N)	Measured: Ratio
Single	33.4	1.0	8.9	1.0
Rectangular	244.8	7.3	71.2	8.0
Square	382.7	11.5	111.3	12.5

The vibration reduction of the resonant shunt technique is dependent upon the tuning of the electrical circuit's resonance to the beam's resonant frequency. Fig.7 also demonstrates that for a lightly damped system (£= 0.5%), vibration control mounts would have pro- vided an approximate 10 dB reduction in the beam's tip velocity.

A degradation in performance is also introduced by inserting a stiff and thick magnet layer in between the piezoelectric element and the beam. Fig.8 shows the tip velocity reduction for different magnet thicknesses and damping ratios. It was assumed that the control mounts were perfectly attached ($k_t = k_v = 10^{15}$ N/m^2) to the beam.

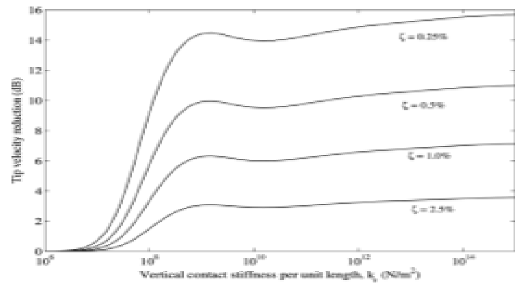

Fig.7 Tip velocity for various contact stiffnesses & damping ratios using resonant shunt control.

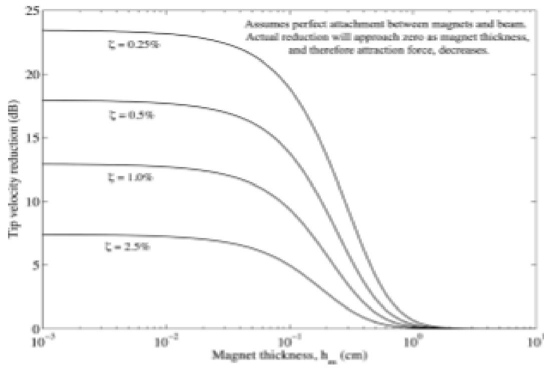

Fig.8 Tip velocity reduction using resonant shunt control for various magnet thickness & damping ratios.

Above figures 7 & 8 indicate that the reduction would have decreased from 17.9 dB to approximately 10 dB with the addition of the magnets. The results demonstrate that the control mounts still provide comparable attenuation albeit not as much when compared to the traditional epoxy mounted piezoelectric elements.

4. Conclusions:

- Piezoelectric elements, most notably lead zirconate titanate (PZT), attenuate vibration by transferring energy between the mechanical and electrical domains of the material.
- A voltage develops across the electrodes when the material deforms and conversely, the elements strain when a voltage is applied across their electrodes and it reduces vibration of the system.
- Piezoelectric elements are typically bonded with epoxy to vibrating structures to provide attenuation. In the event that the elements become damaged or if environmental changes alter structural dynamics, removing and relocating the elements is difficult with such a bond. A viable and adaptable alternative is magnetic-piezoelectric control mounts that attach to the structure through their magnetic attraction. In simulation and laboratory measurements, the mounts provided significant attenuation even with an imperfect bond.

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