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Active Vibration Suppression of Leaf Spring by using Piezoelectric Actuator

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Abstract: An experimental work is conducted on a leaf spring which acts as cantilever smart beam with & without PZT patches, by interfacing the experimental setup. The free vibration of the mild steel, aluminium and GFRP composite beams were carried out by varying the initial displacement and then surface bonded piezoelectric i.e. Lead Zirconium Titanate PZT patches to counteract the vibration levels. An input voltage applied to the PZT in order to find out the settling time and the damping factor of the beams. The first four modes of the natural frequency of smart beams is determined at different position of an actuator from the fixed end of the structure, which are very close to the natural frequency determine by analytical method. There is increase in mass and stiffness of an experimental material, due to addition of the PZT patch on the surface of beam, which results in changes of its natural frequency. The optimization location or position of PZT on the surface is at center of beam length. The leaf spring vibrations signal were collected through a data acquisition system (FFT Analyzer) supported by OROS OX-3 series software. From collected data, post analysis was done and followed by simulation of results with the help of MAT lab software.

Keywords: Leaf spring, Active Vibration, Accelerometer, FFT Analyzer, Lead-Zirconium-Titanate-PZT actuator.

I. INTRODUCTION

Leaf spring are made of flat plates, the ends of the leaf spring are guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device, so that the leaf spring can carry lateral loads, brake torque, driving torque etc. in addition to shock loading. It is commonly used in automobiles is as a semielliptical form, built up of number of plates (leaves), which has initial curvature or cambered, so that they will tend to straighten under the load. The leaf spring absorbs the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection. Leaf springs can serve both damping as well as springing functions. Analysis and suppression of forced vibrations is an important problem in science and technology. control resonance, and prevent structural failures. In doing so, it is often desirable to attenuate or completely suppress the vibrations. Vibration suppression is a broad topic. It is best to start at the source and work down the transmission path when necessary. It is desirable to eliminate or reduce the effects of vibration. When a structure is undergoing some form of vibration, the vibration can be controlled or redesign, by two broadways, one including the use of springs and dampers, which leads to a reduction in the vibration & other one active control, the structure with sensors, actuators and electronic controlsystem, which aim to reduce the measured vibration levels.Advancements in smart materials have produced smaller and effective actuators and sensors with high integrity in structures. Many types of smart materials are well accepted for consideration as actuating and sensing devices, they includes,

1. Piezoelectric (PE),
2. Electrostrictive (ES),
3. Magnetostrictive (MS),
4. Shape memory alloy (SMA),
5. Electro rheological and
6. Fibre optic materials

In general, Piezoelectric and Electrostrictive materials have low saturation strain and force generation, and large percentage of loss of strain unless operated within a very small range of temperature. Return adds an additional weight and volume. Among the many materials, piezoelectric and shape memory alloys are most suitable for active control of the development of smart composite structures. They are able to generate a relatively large deformation. The drawbacks of Shape memory alloy based actuators are comparatively slow response time.

II. LITERATURE REVIEW

D. Rizos. Feltrin, Motavalli.al. (2011), the conventional TMD devices are passive used which be account for the structural modifications of the primary structure under control, followed the method in the natural frequencies of the

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TMDs are distributed over a frequency range by multiple TMDs,the tunable characteristics of the PLA-TMD are achieved by four embedded piezoceramic (PZT) stack actuators, which are capable of providing different axial loading (pre-stress) to the leaf-springs. D. Hwang, S. Lee, and M. G. Lee. (2009).al, they select a target tool with serious vibration level, the design, fabrication, and an experimental result of vibration transmissibility reduction module, implemented by three symmetric flexural leaf springs reduces the vibration transmissibility more than 20%. Jung W.S., S. Bok Choi, H.S. Kim.al. An active vibration control to suppress structural vibration of the smart hull structure's. Balamurugan, S. Narayana (2001). A smart or Composite structure has distributed sensors and actuators and inbuilt control electronics that analyze the response from the sensors and command the actuators using a distributed parameter control theory to apply localized strains, opposing the original deformation of the structure. Saroj Kumar Sarangi, M.C. Ray (2011). A three dimensional finite element model of doubly curved laminated smart composite shells integrated with patches is developed to investigate the performance of patches for controlling the geometrically nonlinear transient vibrations of the shells. Mouleeswaran Senthil kumar. Al. (2010), the vibrations caused by step input on flexible structure (cantilever beam) are actively controlled by using piezoelectric actuators. Vibrations are actively controlled at the free end of flexible structures using piezoelectric actuators. M. Yuvaraja. Senthil kumar, I. Balaguru.al. (2011). The PZT actuators are used for active vibration control. The settling time of the smart structures is decreased and logarithmic attenuation coefficient is also increased by increasing the input voltage to the PZT actuators. The vibrations in a cantilever beam were suppressed by applying variable voltage to the piezoelectric actuator. K.B.Waghulde,Dr. Bimlesh Kumar, T.D. Garse, M.M. Patil.al. (2011), the optimal location of sensor/actuator pairs and design optimal controller for beam, plate and stiffened plate to suppress mechanical vibrations theoretically and experimentally. C.M.A. Vasques, J. Dias Rodrigues.al. (2006) an active structure with a set of sensors to detect the vibration and actuators, which influence the structural response of the system coupled by a controller, to suitably manipulate the signal from the sensor and change the system's response in the required manner. Yuvaraja M., Senthilkumar.M.al. (2012). SMA based and PZT based composites are used for investigating the vibration characteristics. The smart beam consists of a Glass fibre reinforced polymer (GFRP) beam modelled in cantilevered configuration with externally attached SMAs & the smart beam consists of a GFRP beam with surface bonded PZT patches. The vibrational characteristic of GFRP beam is more effective when SMA is used as an actuator.

III. FREQUENCY RESPONSE & ACTUATION

For a simple elastic beam problem with uniform cross-sectional area, a well-known natural,

$$\omega n = \frac{1}{2\pi}(\beta l)^2\sqrt{\frac{EI}{\rho A l^4}} \quad 3.1$$

Where A and l are the area of cross-section and the length of the flexible beam, respectively. βl is a constant relative to the vibration bound condition. The constant βl for first four modes of a cantilever configuration are 1.87504, 4.690491, 7.854757, and 10.995541 respectively. EI is the equivalent bending stiffness. The characterization of the smart materials is their good damping property. Several damping parameters, such as inner fraction, loss factor and loss tangent tan Δ have been used individually or combined for metals, ceramics, and rubbers, according to the material properties and test methods. For the smart materials, the logarithm attenuation coefficient is used, which is evaluated by measuring the vibration amplitude during the experiment.

$$\Delta = \frac{\ln Xn}{Xn+1} \quad 3.2$$

Where Xn and Xn+1 are the amplification of sine wave with logarithm damping in different intervals.

$$\epsilon = \frac{\Delta}{\sqrt{(2\pi)^2 - \Delta^2}} \quad 3.3$$

Table I: Four natural frequencies (Theoretical)

Mode shape	Type of Beam		
	Mild steel	**Aluminium**	**GFRP**
I	2.546	2.572	6.643
II	15.942	16.092	41.563
III	44.706	45.126	116.556
IV	87.606	88.430	228.403

IV. EXPERIMENTAL SETUP

The Experimental set up for this project is as shown in figure 1. A clamped or fixed end and free end of beam fixed horizontally along its width is considered in the set up.

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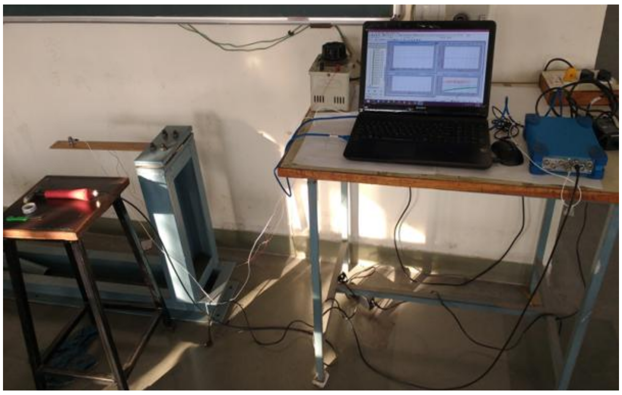

Fig.1.A real-time experimental setup.

The dimensions and material properties of the mild steel, aluminium and GFRP composite beams, along with PZT actuator are listed in Table I and Table II respectively. PZT (Lead Zirconate Titanate) of type SP-5H from Sparkler Ceramics Pvt. Ltd Pune, Maharashtra, is used in an experimental set up. Also it consist of a suspension (semi-elliptical) leaf spring with the externally bonded piezoelectric actuator and the fixture, FFT analyzer, time and actuation circuit, accelerometer, Impact Hammer system with the controller, computer system with interfaced lab view software. Also it consist of a suspension (semi-elliptical) leaf spring with the externally bonded piezoelectric actuator and the fixture, FFT analyzer, time and actuation circuit, accelerometer, Impact Hammer system with the controller, computer system with interfaced lab view software.

Table II: Geometrical dimension of PZT patch

Dimensions of PZT Actuator Patch.		
Patch Length(mm)	L	76.2
Patch Width(mm)	W	25.4
Patch Thickness(mm)	T	0.5

Table: III Cross Section of Beam Material

Cross Sectional Dimension	**Mild Steel**	**Al**	**GFRP**
Length (m)	0.4	0.4	0.4
Width (m) (b)	0.05	0.05	0.05
Thickness (m) t	0.005	0.005	0.005
Young's modulus (GPa) E	200	70	52.36
Density (kg/m3) ρ	7850	2700	1980
Volume fraction of Glass Fibre(VGlass)	---	---	0.6

V. RESULTS & DISCUSSION

The free vibration of the mild steel, aluminium and GFRP composite material beams were carried out by varying the initial displacement and input voltage to the PZT.For maximum effectiveness the actuators is placed in high strain regions and away from areas of low strains. The results were called for the post analysis process using FFT analyzer and results were analyzed for the preset displacement value of 40 mm. 50 mm and 60 mm displacement. Signal or the results obtained after the post analysis process, the settling time of each beam in terms of graphs as displacement versus time, and then it is followed by the simulation of each result at different position by using MAT lab software.

A.Without Pzt Actuator Test.

A set of experiments with set of readings at each position is conducted with leaf spring eye joint or the free end in suspension system. The selection of acceleration transducer with its physical quantity and range. The modal hammer with controller excites the structure with a constant force over a pre- selected frequency range, windowing, and band width, start and stop delay times.

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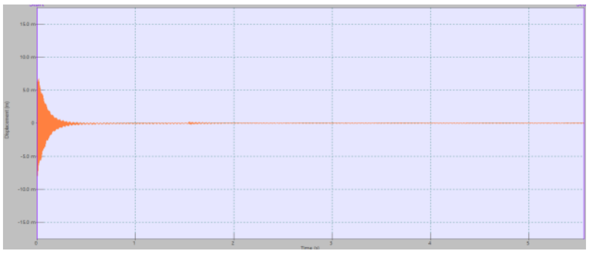

Fig.2. Mild Steel beam without PZT actuator at 40 mmdisplacement (Free end).

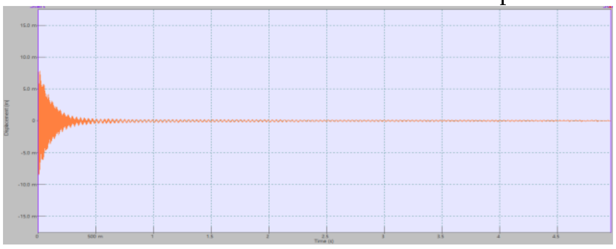

Fig. 3.Mild Steel beam without PZT actuator at 50 mmdisplacement (Free end).

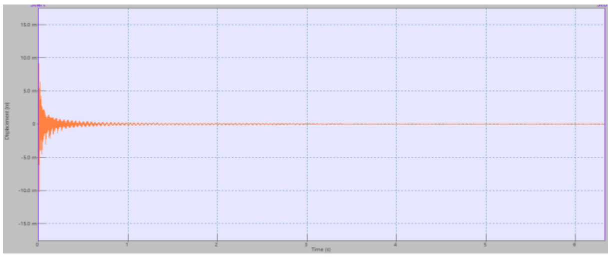

Fig. 4.Aluminium Beam without PZT actuator 40 mm displacement (Free end)

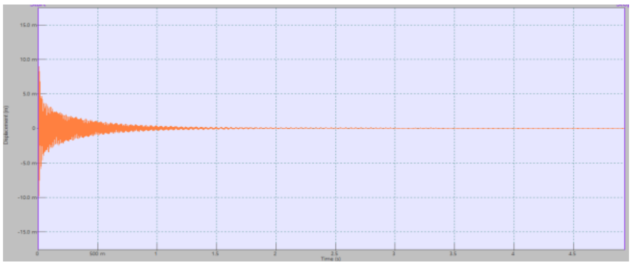

Fig. 5.Aluminium Beam without PZT actuator 50 mmdisplacement (Free end)

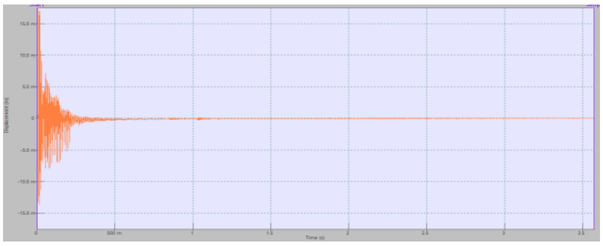

Fig.6.GFRP Composite Beam without PZT actuator 40 mmdisplacement (Free end).

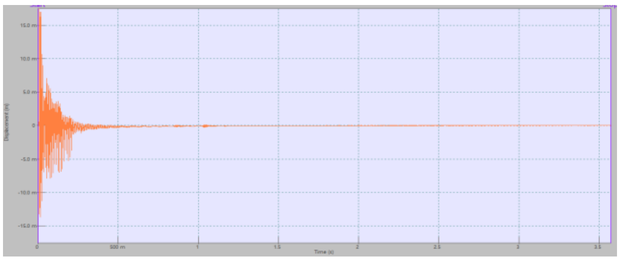

Fig.7.GFRP Composite Beam without PZT actuator 50 mmdisplacement (Free end)

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B.With Pzt Actuator Test.

In this set of experiments, the leaf spring is clamped with PZT actuator (Dynamic Analysis) (damping), then the same set of experiments were repeated as given in previous section and vibration signals were collected with use of PZT actuator (damping). The PZT patch was glued to the surface of the beam at centre of the experimental material beam.

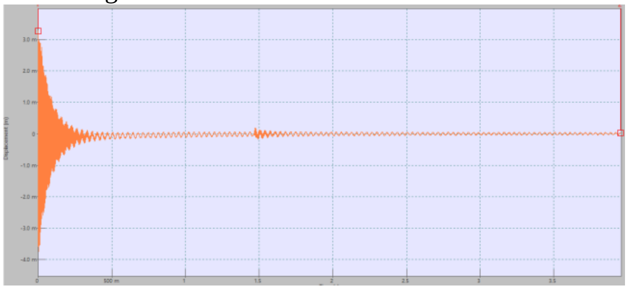

Fig. 8.Mild Steel beam at 0 volt 40 mm displacement.

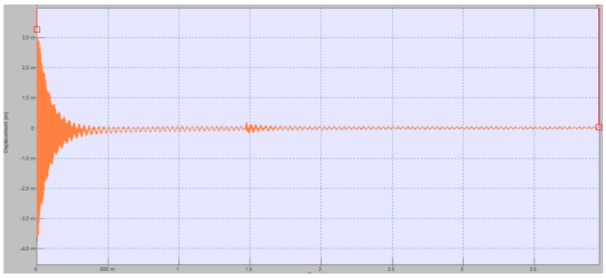

Fig. 9.Mild Steel beam at 0 volt 50 mm displacement.

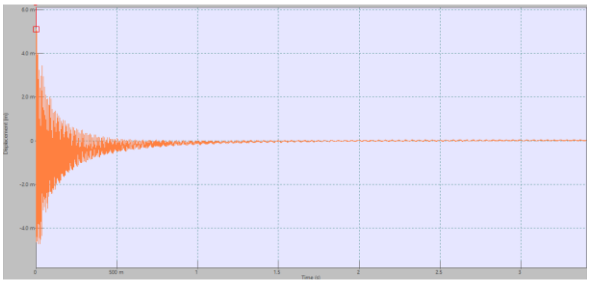

Fig.11.Aluminium beam at 0 volt 40 mm displacement

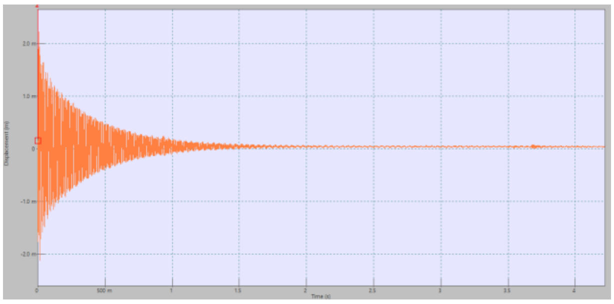

Fig. 12.GFRP Composite beam at 0 volt 40 mm displacement

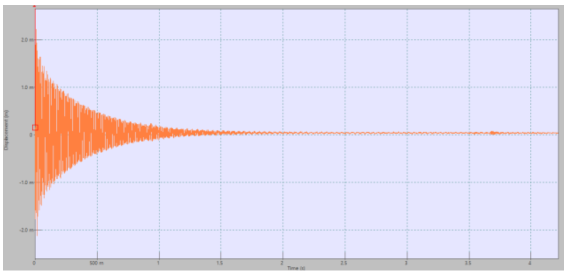

Fig.13.GFRP Composite beam at 0 volt 50 mm displacement

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C.Logarithmic Attenuation (Damping)

The damping factor for aluminium is greater than that of mild steel which causes the vibrations to decay sooner. Due to the higher mass of mild steel than aluminium, the inertial forces are high, resulting in higher settling time. Also the higher stiffness of mild steel, reduces the effect of PZT actuator in vibration damping. All these reasons account for greater settling time in mild steel than in aluminium. The settling times for various initial displacements were compared for various voltage input to the PZT patch.

Table: 6.5. Damping Factors 0 to 90 volt.

Beam materials	Damping factor ζ			
	0 Volt	30 Volt	60 Volt	90 Volt
Mild Steel	0.0386	0.0447	0.0451	0.0455
Aluminium	0.0394	0.0440	0.0475	0.0481
GFRP	0.0400	0.0480	0.0495	0.0500

It is clear from the theoretical and experimental analysis that, the mass and stiffness has great influence on the magnitude of the natural frequency of the particular material, thereby it indirectly affect the settling time or the damping characteristics of the material. The patching of the PZT actuator on the surface of the Mild steel, Aluminium and GFRP composite beam influence the mass and stiffness of each material. Addition of the PZT actuator or patch on the surface of each beam adds some material, which results in increased in percentage of mass and stiffness. Due increased in percentage of mass and stiffness, mild steel beam material has high inertial values than aluminium. For the same voltage (0-90 volt) of PZT actuator the settling time of mild steel beam material is high as compared aluminium, so the settling time is also high, which results in low damping effect by the PZT actuator on mild steel as compared to aluminium. Due to low mass and stiffness of the GFRP Composite beam as compared to mild steel and Aluminiumbeam material. So the, GFRP composite beam material has low inertial forces values than mild steel and aluminium.

VI. CONCLUSION

The settling time of GFRP composite beam material is considerably low as compared mild steel and aluminium, which results in high damping effect by the PZT actuator on GFRP composite beam material as compared to mild steel and aluminium. The damping effect of the PZT actuator on the GFRP composite beam is observed to be more than aluminium beam and mild steel beam respectively, because due to higher inertial forces values in the aluminium and then Mild steel, there is less response to PZT actuation for the same voltage.

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