

Active Vibration Control of a Fixed Beam using PZT Patches

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ABSTRACT: Piezoelectric materials have the ability to produce a contraction or extension when an electrical charge is applied to them. By integrating piezoelectric elements into slender structures, structural vibration and oscillations can be reduced by measuring them and actuating in real time. In this paper, two pairs of PZT patches are used to study the Active vibration control. The position of the PZT sensors and actuators is found out by using software ANSYS. The Active Vibration control of fixed beam is done by using PZT patches as sensor and actuator. The vibrations induced in the beam due to wind are suppressed by the actuators.

KEYWORDS: Vibrations, Sensors, Actuators, Controller, PZT, smart structure, ANSYS, Oscilloscope.

I. INTRODUCTION

The motivation for this work checks the possibility of using induced strain actuation for vibration suppression, stability accretion, and noise deduction in beam-like aerodynamic surfaces. While building the beam, it is taken into consideration that piezoelectric materials must be bonded to the beam in a uniform fashion along with the fact that both materials must have electrical contact on each side of the material. For piezoelectric actuators surface bonding is advantageous as there is better access for fabrication, easier access for inspection, and less maintenance cost. However, as these materials are exposed, they are more susceptible and more prone to be damaged. But, in this type of experiment, it is peremptory for the piezoelectric components to be on the surface because it was the only way it could be easily manufactured.

A smart structure has the following components:

Sensor(s): It generates signal proportional to the changing property that can be measured according to environmental changes.

Actuator(s): in order to achieve the desired response, actuators are used to change the properties of the smart structure

Control System(s): In order to determine if any action is required, control systems incessantly monitor the sensor's signal, process the information and in case if action is required, then a signal is applied to the appropriate actuator(s).

If the set of actuators and sensors can be treated separately in case they are located at discrete points of the structure. From a mechanical point of view, for classical structural materials as elastic constants relating stress and strain, and their thermal expansion coefficient relating the strain to the temperature describes their properties. While in case of smart material, strain can also be generated by different mechanisms involving electric field, magnetic field, temperature, etc. as a result of some coupling in their constitutive equations.

II. LITERATURE REVIEW

There are many authors who have worked on suppressing the vibrations actively of cantilever beam. Omer Faruk Kirkali et al. [1] presented mathematical modeling of the smart beam conducted by using the assumed-modes method. This resulted in a higher order model including a large number of resonant modes of the beam. By including only the first two flexural vibrational modes of the smart beam the higher order model was truncated to a lower model. By employing a model correction technique which considered the addition of a correction term that consequently

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Vol. 5, Issue 8, August 2016

minimized the weighted spatial 2 H norm of the truncation error the possible error due to that model truncation was compensated. Hence, the effect of out-of range modes on the dynamics of the system was included by the correction term.

A class of resonant controllers for minimizing vibrations of flexible structures using collocated piezoelectric actuator-sensor pairs was introduced by Dunant Halim et al. [2]. The resonant responses of a chosen number of vibration modes are minimized by the controller. The controller structure should be such that the closed loop stability is guaranteed.

Paolo Gaudenzi et al. [3] the problem on the attenuation of the vibration effects in cantilever beams. They simulated the problem numerically and analyzed experimentally. A finite element approach based on an Euler-Bernoulli model and subsequent modal factorization is used for the numerical simulation. The results of the numerical simulation have been compared to those ones obtained with the experimental tests and a good correspondence has been obtained in the three cases. Besides, the analysis has demonstrated the better effectiveness of the position control respect to the velocity control as strategy to reduce the vibration levels in a cantilever beam.

Balamurugan et al. [4] presented a paper which dealt with the active vibration control of beam like structures with distributed piezoelectric sensor and actuator layers bonded on top and bottom surfaces of the beam. They developed a finite element model which is based on Euler-Bernoulli beam theory. Here, they considered the contribution of the piezoelectric sensor and actuator layers on the mass and stiffness of the beam. Direct promotional feedback, constant-gain negative velocity feedback and Lyapunov feedback these three types of classical control strategies and an optimal control strategy, linear quadratic regulator (LQR) scheme are applied to study their control effectiveness. Also, the control performance with different types of loading, such as impulse loading, step loading, harmonic and random loading is studied.

In the paper of Yavuz Yaman et al. [5] the smart plate consists of a rectangular aluminum plate modeled in cantilever configuration with surface bonded piezoelectric patches. The patches were symmetrically bonded on top and bottom surfaces. ANSYS (v.5.6) software was used to derive the finite element model of the smart plate. The study first gave the influences of the actuator placement and size on the response of the smart plate and determined the maximum admissible piezoelectric actuation voltage. The optimal sensor locations are found and actual smart plate is produced. These experimental results of the smart plate are then used to determine a single input single output system model.

Melin Sahin et al. [6] presented the theoretical and experimental studies conducted in Aerospace Engineering Department of Middle East Technical University on smart structures. They gave particular attention to the structural modeling characteristics and active suppression of in-vacuo vibrations. The smart structures considered in these analyses are flat aluminium cantilever beam-like and plate-like structures with surface bonded PZT patches. Finite element models of smart beam and smart fin are obtained. The experimental readings are taken to study regarding open loop behavior of the structures performed by using strain gauges and laser displacement sensor to determine the system models.

A. Benjeddou et al. [7] presented a paper on finite element model for adaptive sandwich beams to deal with either extension or shear actuation mechanism. Based on Bernoulli-Euler theory for the surface layers and Timoshenko beam theory for the core the mechanical model was developed. Three variables, through-thickness constant deflection, the mean and relative axial displacements of the core's upper and lower surfaces were used. The piezoelectric effect is handled through modification of the constitutive equation, when induced electric potential is taken into account.

M. Yaqoob Yasina et al. [8] worked on the active vibration control of smart plate which was equipped with patched piezoelectric sensors and actuators. To model the kinematics of the plate and to obtain the shear strains, an equivalent single layer third order shear deformation theory is employed. They considered the linear variation of electric potential across the piezoelectric layers in thickness direction. Undamped natural frequencies and the corresponding mode shapes are obtained. The finite element model in nodal variables are transformed into modal model and then recast into state space. The dynamic model is reduced for further analysis using Hankel norm for designing the controller. To control the vibration of the plate the optimal control technique is used.

Chang Zheng et al. [9] used impedance method and FEM to simulate beams with piezoelectric actuators. Very first, to describe the dynamic of one piezoelectric stretch actuator one impedance matrix equation is used and each impedance equation is equivalent to one (M-C-K) mass-damping-spring system. Secondly, to build FE model of beams driven by piezoelectric bending actuators the equivalent system is used.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

How to obtain optimal location and size of PZT actuators is studied by Jingjun Zhang et al [10]. According to the method of model reduction based on the truncation criterion of modal cost, the model of a piezoelectric smart structure is built by the application of ANSYS software which extracts the required modes, then, both the optimal location and the size of piezoelectric actuators can be ascertained by these extracted modes.

K. B. Waghulde et al. [11] made a setup comprised of actuators and sensors placed at the root of a cantilever beam. Vibrations were given by various sources including human activity and nearby motorized equipment. With help of white noise signal actuator disturbance is produced. Feedback controller sends correction information to the actuator that minimizes the vibration. To optimize results, controllers were designed using Linear Quadratic Gaussian (LQG) theory.

C. van Gemert et al. [12] and Serge study is concerned with nature conservation by automatically monitoring animal distribution and animal abundance. The camera mounted on it uses passive vibration control like by using foam. But still some images taken with this type of arrangement are not clear. For this purpose smart structure pizo-laminated beams are used to control the vibrations of camera.

III. METHODOLOGY

The methodology used in the presented work is explained in steps as below:

A) Objectives:

- To control vibrations of smart beam actively by using PZT sensors and actuators.
- To find out optimum position for PZT Patches for maximum vibration control.
- To find out the effectiveness of PZT patches with PID controlling system

B) Problem Statement:

Drones are used for the monitoring purpose of animals. The camera mounted on it uses passive vibration control like by using foam. But still some images taken with this type of arrangement are not clear. For this purpose smart structure pizo-laminated beams are used to control the vibrations of camera. So, the problem is to optimize the location of PZT patch with the aid of simulation solver and to conduct the experiments. So as to use small patches instead of using complete lamination of Pizo on beam for maximum control of vibration for fixed beam. Many of the authors have studied on Cantilever beam. So, here fixed beam is taken as experimental work.



Fig. 1. Drones facing Vibration due to air.

The above figure shows the application active vibration control of fixed beam where the beam having camera fixed on it is considered as fixed beam.

[C] Specification of Experimental Set-up

Dimensions of the beam are as follow

Size of Aluminium beam: 300mm*37mm*2mm

Size of PZT Patch: 25mm*25mm*0.5mm

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

Vibration Exciter: Motor with 1500rpm

[D] Selection of Material:

According to availability and suitability to the project study materials are selected. The Properties are as follow.

Material: Aluminium

Young's Modulus = 67500 N / mm².

Poisson's Ratio = 0.34

Material: Piezoelectric (CaTiO₃)

Young's Modulus = 63000 N / mm².

Poisson's Ratio = 0.31

[E] FEA Analysis for static Loading

ANSYS 14.5 solver is used to analyse the fixed beam. The maximum strain area is suitable for the optimum location for the Sensors and Actuators. As it gives maximum controlling effect.

For both Aluminium beam and PZT Patch 3D SOLID, 8 NODE 185 element type is used.

Loading and Boundary Conditions of beam

Force Acting at the middle of beam = 10 N.

The model is fixed in all three directions at both end (F_x=0, F_z=0, F_y =0).

Applying above inputs the results obtained are as shown in the following figures. From the Subgrid Solution as shown in figures, the strain values at different node positions is greater in case of the beam having patches which are 10mm apart from the fixed ends.

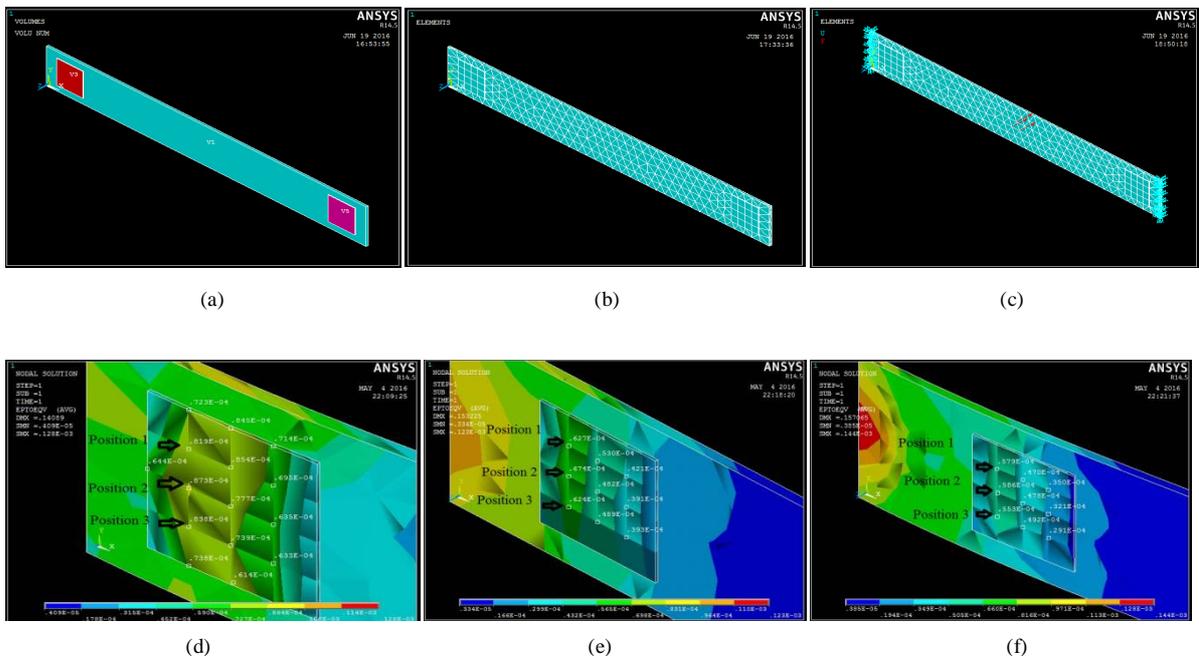


Fig. 2. FEA Analysis (a) Modelling (b) Meshing (c) Boundary Condition and Loading Condition (d) Total Mechanical Von-Mises Strain when patches at 10 mm apart from fixed ends (e) Total Mechanical Von-Mises Strain when patches at 20 mm apart from fixed ends (f) Total Mechanical Von-Mises Strain when patches at 10 mm apart from fixed ends.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

The above figures show the FEA analysis of fixed beam using ANSYS Solver. Fig. 2 (a) shows modelling of beam using 3D SOLID, 8 NODE 185 element type. Fig. 2 (b) shows meshing of the geometry. Fig. 2 (c) shows loading and boundary conditions of the beam. As beam is considered as fixed beam, at both the ends, $F_x=0$, $F_z=0$, $F_y=0$ is applied and Load of 10N is applied at the middle. Fig. 2 (d, e, f) are the total Mechanical Von-Mises strain for three different positions i.e. when patches are at 10mm, 20mm and 30mm respectively, apart from the fixed ends.

TABLE 1			
RESULT TABLE FOR FEA ANALYSIS			
Position	Patch 10 mm apart	Patch 20 mm apart	Patch 30 mm apart
Position 1	0.819e-4	0.627e-4	0.579e-4
Position 2	0.873e-4	0.674e-4	0.586e-4
Position 3	0.838e-4	0.624e-4	0.553e-4

The above table shows the result table for FEA Analysis where each column gives the value of total Mechanical Von-Mises strain at different positions analysed. This is obtained by using subgrid solution at different node points.

IV. EXPERIMENTAL SET-UP AND TESTING

[A] Introduction:

A smart beam is produced as a test specimen to be used in the experiments for the comparison with simulation results. The smart beam consists of an aluminium beam, piezoelectric patches as an actuator, and a sensor. The piezoelectric actuator and sensor is bonded onto beam using conductive epoxy. A wire is soldered on the piezoelectric actuator. PID Controller is used. A fixed beam is manufactured to provide boundary and initial conditions at both ends of the smart beam.

The test setup block diagram and the photograph are shown as below.

[B] Test Procedure:

Test setup as per photographs shown above.

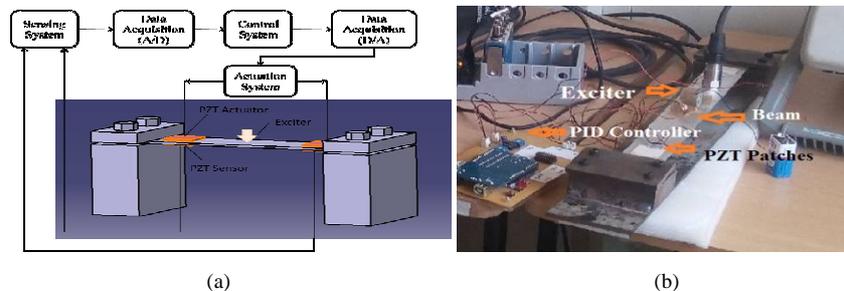
Start the motor to excite the beam.

Run the serial oscilloscope and start logging file in csv format.

Take readings with actuator's pins inserted in PID controller for 1 min.

Take readings without actuator's pins inserted in PID controller for 1 min.

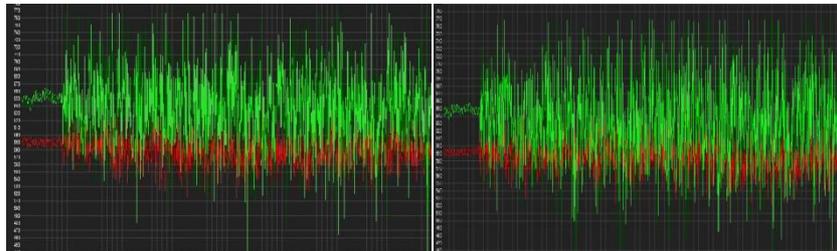
Repeat the procedure for 3 times and analyse the data which will be available in logged files.



International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016



(c)

(d)

Fig. 3. (a) Experimental Set-up Block Diagram (b) Photograph of Experimental Set-up (c) Serial Oscilloscope reading with Actuation (d) Serial Oscilloscope reading with Actuation

Fig. 3 (a) shows the block diagram of general concept of how the actual experimental set-up would be. Fig. 3 (b) shows the actual photograph taken when the experiments were performed. Fig. 3 (c & d) show the Oscilloscope output readings screenshots taken when the serial oscilloscope is used for two conditions i.e. with actuation and without actuation respectively.

TABLE 2				
RESULT TABLE FOR EXPERIMENTAL READINGS				
Condition of set up	Average of amplitude for Sensor 1 (mV)	Average of 3 readings	Average of amplitude for Sensor 2 (mV)	Average of 3 readings
With Actuation 1	31.49		76.04	
With Actuation 1	25.44	28.85	73.19	74.41
With Actuation 1	29.64		74.01	
Without Actuation 2	31.33		86	
Without Actuation 2	30.15	30.69	84.87	85.6
Without Actuation 2	30.59		85.95	

The above table shows result table of the readings taken during the experimental work. Three readings were considered for each of the condition i.e. with actuation and without actuation. For these readings, average is considered for the results.

Reduction of amplitude in % for sensor 1

$$= \frac{[30.69-28.85]*100}{30.69} = 6\%$$

Reduction of amplitude in % for sensor 2

$$= \frac{[85.6-74.41]*100}{85.6} = 13.08\%$$

Log files are recorded and saved in csv format, so as to have excel sheet. These readings are analyzed and graphs are taken which are as shown in fig. Later amplitude is determined by taking average of these readings. Further with actuation and without actuation results are compared. So, by using PZT patches, reduction in vibration is 6% for one sensor and 13.08% for another sensor.

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 5, Issue 8, August 2016

V. CONCLUSION

Based on comparative study material selection for both beam and PZT patches, method of experimentation has been finalized. The position of PZT patch is determined by doing analysis of the smart structure in ANSYS14.5. As it indicates the maximum total mechanical Von-Mises strain. Experimental set up has been developed to study the active vibration control of a beam fixed at both ends. The results obtained from the serial oscilloscope conclude that PZT can suppress the vibration actively and can be used in the drone.

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