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Finite Element Analysis of PVDF Actuated Cantiliver Beams

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Abstract:
Considerable attentions have been devoted recently to active vibration control using smart materials as actuators. This study presents an active vibration control technique applied to a smart beam. The goal of the work is to theoretically investigate the behaviour of piezoelectric polymer film. PolyVinyliDene Fluoride (PVDF) is polymer film, which is flexible and lightweight plastic material which is well known for Transducer application. The smart beam consists of Aluminium and mild steel beams modelled in cantilevered configuration with surface bonded PVDF patches.

***Key words**: Active Vibration Control, PVDF, ANSYS*

1. Introduction

To get an idea of how smart structures can be implemented, it is necessary to understand the fundamental components of these structures: sensor and actuator materials.

For centuries, materials have been known to react to the surrounding environment producing some form of response. For instance, in 1824, Rochelle salt was discovered to become electrically polarized by the application of heat. That was the first discovery of the effect known as Pyro electricity. Since that time, numerous additional materials have been discovered having the inherent capability to convert one form of energy into another. Sensors are materials that respond to a physical stimulus, such as a change in temperature, pressure, or illumination, and transmit a resulting signal for monitoring or operating a control. Actuators are materials that respond to a stimulus in the form of a mechanical property change such as a dimension or a viscosity changes.

2. Theoretical Analysis

A. Resonant Frequencies of Bending Modes of the Cantilever Beam From the dimensions of the cantilever beam without crack, we can see that the length is ten-fold larger than the width, and the width is ten-fold larger than the thickness. Hence, the theory of Bernoulli-Euler beam can be applied to analyse the resonant frequency of the cantilever beam. For a simple elastic beam problem with uniform cross-sectional area, a well-known natural frequency can be calculated by Bernoulli-Euler beam equation which is expressed below.

$$\omega n = 1/ 2\pi (\beta l)2 [\{EI / \rho A l4 \}]^{1/2} \qquad (1)$$

In which is
E = Young’s modulus, in Gpa
ρ = density in Kg/m^2
I = Moment of inertia in mm^4.

Where A and l are the area of cross-section and the length of the flexible beam in mm, respectively. βl is a constant relative to the vibration bound condition. The constant βl for first six modes of a cantilever configuration are 1.87504, 4.690491, 7.854757, 10.995541, 14.137 and 17.279 respectively. EI is the equivalent bending stiffness.

From the geometrical dimensions and material properties of the cantilever beam, the natural frequencies of the bending modes of the cantilever beam can be evaluated. In addition, by exchanging the width b, and thickness h of the cantilever beam, we can get the natural frequencies of lateral modes of the cantilever beam.

B. Resonant Frequencies of Torsional Modes of the Cantilever Beam
The equation of motion of a cantilever beam for torsional modes is expressed below.
$f_n = (2n+1) / 2L \;\; b/c \;\; \sqrt{(G/ \rho)}$ (2)
Where G is the shear modulus of the cantilever beam.

3. FEM Analysis

In the present analysis the finite element modelling is mainly done using ANSYS software. The model considered for the analysis is Cantilever Beam, one is an Aluminium Beam and other is a steel Beam of dimensions as specified in the figure below. The analysis is done by taking a three dimensional section of these Beams , which is treated to be in axissymmetric condition as shown in fig 1 and the Natural Frequency are calculated by the equations provided by [1]and is calculated in the further steps.

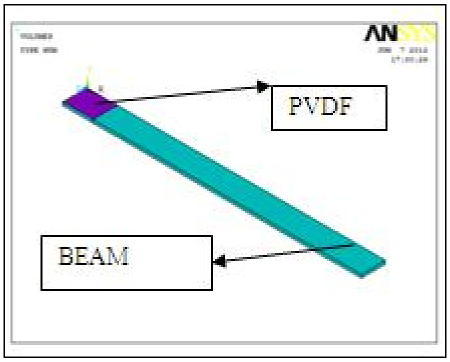

Figure 1: ANSYS Modelling of PVDF Bonded Beam

3.1. Modal Analysis

Modal analysis is the process of determining the inherent dynamic characteristics of a system in the forms of natural frequencies, damping factors and mode shapes, and using them to formulate a mathematical model for its dynamic behaviour. The formulated mathematical model is referred to as the modal model of the system and the information for the characteristics is known as its modal data. A plot is then generated for natural frequency vs time, then different mode shape, s are obtained for different natural frequencies which include twist and bending modes.

3.2. Static Analysis

Statics is the branch of mechanics that is concerned with the analysis of loads (force and torque, or "moment") on physical systems in static equilibrium, that is, in a state where the relative positions of subsystems do not vary over time, or where components and structures are at a constant velocity. When in static equilibrium, the system is either at rest, or its centre of mass moves at constant velocity.in this work by using this analysis

- Determination of displacement by varying the voltage.
- Determination of displacement by changing the position of PVDF

Extension Actuation Mechanism (EAM)

In this type of actuation mechanism electrodes on the bottom surfaces of the extension actuators are assumed to be grounded. Electrical potentials of positive and negative polarities are applied on the top surfaces of top and bottom extension actuators to achieve bending effect. The direction of application of the electric field with induced polarization direction coincides and both are in the same plane. In the clamped-free condition the cantilever Beam with extension actuators is clamped at one end and other end is free. Top surface of extension actuators are subjected to +25V, +50V, +75V, and +100V respectively and bottom surface of actuators are grounded.

4. Result and Discussion

Properties		**Al**	**STEEL**	**PVDF**
Young's modulus(GPa	E	69	200	2
Shear modulus(GPa	G			
Poisson's ratio	Y	0.33	0.33	0.33
Density (Kg/m3)	ρ	2700	7800	1780
Piezo electric Constant	D31	0	0	0.044
	D32			0.006
	D33			-0.06

Table 1: Material Properties

Details	Notations	Dimensions In (mm)
Length of Beam	L	148
Width of Beam	b	12
Thickness of beam	t_b	1.6
Thickness of actuator	t_a	$28*10^{-3}$
Size of actuators	L_a*b_b	15*12

Table 2: Dimensional Details

Case 1: Modal Analysis

Finding the natural frequency of PVDF Actuated an Aluminium / steel cantilever beam using solid element is subjected to modal analysis. The Beam is clamped at one end and the other end is free. First 10 non-zero frequencies and the respective mode shapes are shown below.

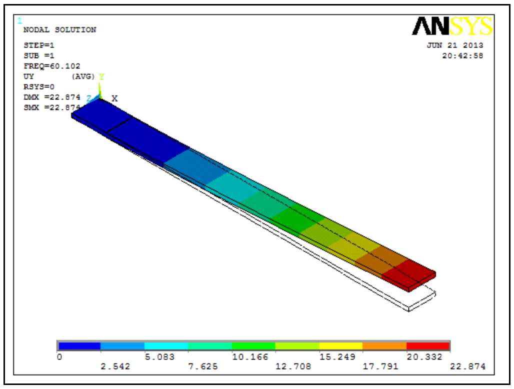

Figure 2: 1st Mode Shape of AL Beam

Set	Frequency in (Hz)	
	Al	Steel
1	60.102	60.192
2	376.38	376.99
3	1053.5	1057.8
4	1357.3	1359.7
5	1927.6	2103.0

Table 3: Frequency Comparison

Case 2: Static Analysis

Finding the maximum displacement of PVDF Actuated an Aluminium / steel cantilever beam using solid element is subjected to modal analysis. The Beam is clamped at one end and the other end is free. Top surface of extension actuators are subjected to +25V, +50V, +75V, and +100V respectively and bottom surface of actuators are grounded.

Set	Deflection in (mm)	
	Al	Steel
25v	0.470e-4	0.162 e-4
50v	0.940e-4	0.325 e-4
75v	0.141e-3	0.487 e-4
100v	0.188e-3	0.649 e-4

Table 4: Deflection of Al and Steel Beam

Case3: INFLUENCE OF POSITION OF PVDF ACTUATOR ON NATURAL FREQUENCY / DISPLACEMENT

The PVDF actuator patch is surface bonded at different locations from the fixed end. The vibration characteristics of the Aluminium and Mild steel beam with PVDF actuator is investigated by bonding the PVDF patches at different locations and voltage given to PVDF actuator is varied. The influence of location of the PVDF patch onto the surface of the beam was studied separately for mild steel and aluminium. The smart beam was divided into five equal segments. The first segment, located at the fixed end of the beam the fifth segment, located on the free end of the beam the beam and the PVDF patch were modelled in ANSYS and were glued together and analysed for displacement with fixing the beam at one end. The ANSYS models of beam with PVDF patches at various locations. Due to the addition of PVDF patch on the mild steel and aluminium beams the mass and stiffness of the beam gets increased but not proportionally. Deflection distributions for actuator patch locations; at the fixed end, at the distances of 29.5 mm, 66.5 mm and 103.5 mm and 140.5 from the fixed end are obtained from ANSYS. AS Shown Below

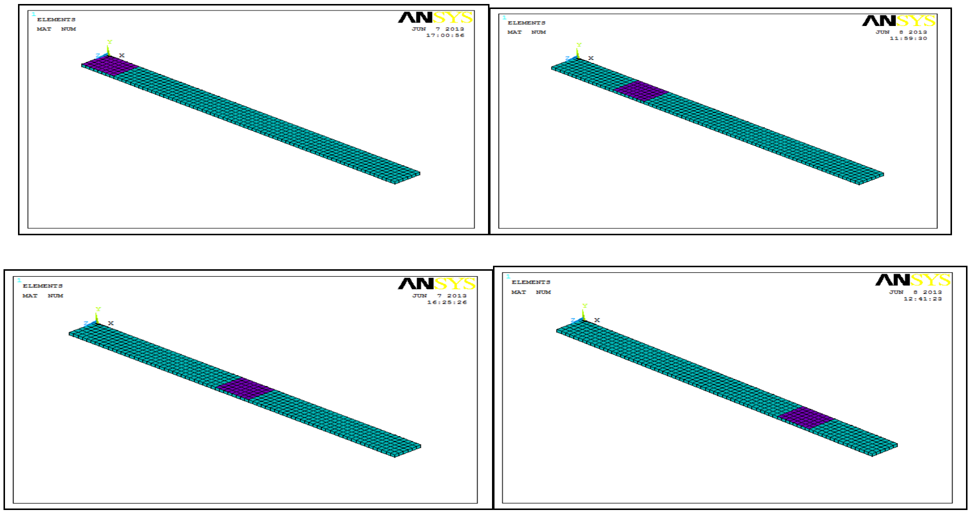

Figure 3: PVDF Patches at Various Locations

set	Location of PVDF Actuator (centre point) in mm				
	7.5 (mm)	29.5 (mm)	66.5 (mm)	103.5 (mm)	140.5 (mm)
	Frequency in (Hz)				
1	60.102	60.098	60.074	60.032	59.985
2	376.102	376.15	376.55	376.35	378.46
3	1053.5	1081.9	1054.0	1054.3	1088.0
4	1357.3	1359.4	1359.0	1357.1	1361.6
5	1927.6	2104.2	1619.4	1473.9	1448.4

Table 5: Frequency Comparisons of the First Ten Non- Zero Frequencies of the Al Beam

set	Location of PVDF Actuator (centre point) in mm				
	7.5 (mm)	29.5 (mm)	66.5 (mm)	103.5 (mm)	140.5 (mm)
	Frequency in (Hz)				
1	60.192	60.192	60.187	60.173	60.160
2	376.99	377.88	377.42	376.98	378.39
3	1057.8	1084.4	1055.8	1056.5	1077.8
4	1359.7	1361.7	1361.7	1360.3	1361.1
5	2103.0	2108.9	1622.5	1477.3	1466.8

Table 6: Frequency Comparisons of the First Ten Non- Zero Frequencies of the Steel Beam

Voltage Applied	Location of PVDF Actuator (centre point) in mm				
	7.5 (mm)	29.5 (mm)	66.5 (mm)	105.5(mm)	140.5(mm)
	Deflection in (mm)				
25v	0.477e-3	0.887e-3	0.591e-3	0.106e-3	0.669e-3
50v	0.940e-3	0.158e-3	0.118e-2	0.221e-3	0.134e-3
75v	0.141e-2	0.266e-2	0.179e-2	0.319e-2	0.200e-3
100v	0.188e-2	0.355e-2	0.237e-2	0.425e-3	0.268e-3

Table 7: Deflection of Al Beam

Voltage Applied	**Location of PVDF Actuator (centre point) in mm**				
	7.5 (mm)	29.5 (mm)	66.5 (mm)	105.5(mm)	140.5(mm)
	Deflection in (mm)				
25v	0.162e-3	0.306e-3	0.654e-2	0.307e-4	0.231e-4
50v	0.325e-3	0.613e-3	0.161e-3	0.734e-4	0.462e-3
75v	0.487e-3	0.919e-3	0.196e-3	0.110e-3	0.693e-4
100v	0.649e-3	0.123e-3	0.262e-3	0.147e-3	0.924e-3

Table 8: Deflection of Al Beam

set	**Frequency in (Hz)**			
	Modes	**FEM**	**Theoretical**	**% Error**
1	Bending	60.102	59.66	0.74
2	Bending	376.38	372.89	0.83
3	Bending	1053.5	1045.75	0.74
4	Torsional	1357.3	1395.13	-2.71
5	Bending	1927.6	1915.8	0.61
6	Bending	2064.9	2049.58	0.5
7	Bending	3418.9	3396.310	0.66
8	Torsional	4087.5	4185.39	-2.33
9	Bending	5130.4	5060.35	1.38
10	Torsional	6873.6	6975.655	-1.48

Table 9: Frequency Comparison of Theoretical results with FEM for Al Beam

	Frequency in (Hz)			
set	Modes	FEM	Theoretical	% Error
1	Bending	60.192	59.81	0.63
2	Bending	376.99	373.866	0.83
3	Bending	1057.8	1048.525	0.88
4	Torsional	1359.7	1398.30	-2.76
5	Bending	2103.0	2054.58	2.35
6	Bending	2570.7	2520.4	1.99
7	Bending	3600.3	5074.64	6.00
8	Torsional	4122.0	4195.37	-1.74
9	Bending	5645.1	5074.7	11.24
10	Torsional	7100.9	6992.30	1.55

Table 10: Frequency Comparison of Theoretical results with FEM for steel Beam

5. Conclusion

Coupled field finite element modelling of PVDF Actuated Beam is carried out. The piezoelectric extension actuators provided in the beam support the d31 based EAM. The actuation performance of the beam is investigated with the C-F boundary condition and under different actuations. Smart materials will control the system in terms of reducing the vibrations amplitude and frequency so as to improve the efficiency of the system. The design, characterization and testing of the PVDF actuator for vibration control applications has been presented. In this study, it can be found that the PVDF actuators can be used for active vibration control. The positions of actuators have a critical influence on the natural frequencies of smart structures. For maximum effectiveness the actuators must be placed in high strain regions and away from areas of low strains. Thus the vibrations in a cantilever beam were suppressed by applying variable voltage to the piezoelectric actuator.

These aspects are studied as a part of an investigation of the influence of actuators on the actuation performance. Some of the important findings of the study are as follows.

- Bonding of extension actuators on the surface of beam increases stiffness marginally, this leads to increase in natural frequency.
- Change in the natural frequencies is noticed due to the change in position of the actuator; nevertheless first three natural frequencies remain unchanged.
- There is a decrease in natural frequencies with increase in the voltage Application to the actuators.
- The deflection values of SAM will decrease when the modulus of elasticity of material increases.
- The stiffness of beam increases with the increases in the Voltage Application to the extension actuators.

The authors Chetan Byrappa , Dr. Ajay Kumar B.S, Dr. H.N Jagannatha Reddy*and Anupama Hanumaiah*1 declares that there is no conflict of interests regarding the publication of this article.

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