International Journal of Emerging Engineering Research and Technology
Volume 2, Issue 7, October 2014, PP 220-230
ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online)

Analysis of Active Control of Force Vibration in Composite Beam

Asst.Prof. Kale D R[1], Prof. Anup Ghosh[2]

[1]Department of Mechanical Engg, Dr D Y Patil School of Engg, Pune, India
[2]Department Aerospace Engg, IIT Kharagpur, Kharagpur, India

Abstract: *This paper deals with the active control of forced vibration in composite beam using piezoelectric material. Composite beam with different boundary conditions are modelled in ABAQUS 6.7FEA analysis software. The model is studied for different laminate sequences and boundary conditions. A comparison study is carried out for different types of composite also*

Keywords: *Active vibration, composite, piezoelectric, FEA*

1. Introduction

Vibration suppression of flexible structure has received considerable attention in recent years. Piezoelectric ceramic materials are efficient in conversion of electrical energy and mechanical energy, and easy integration with various metallic and composite structures. When a flexible system is subjected to external disturbances, vibration can be produced. This vibration can reduce system performance and may result in hazardous condition normally associated with decreased fatigue life and structural failure. Advanced composite structure incorporating piezoelectric sensor and actuators are increasingly becoming important because of development of smart structure. These structures offer potential benefit in wide range of engineering applications such as vibration suppression, precise positioning.

One of the pioneering works in piezoelectric structure is due to Moita and Soares [3] who developed finite element formulation for active control of forced vibration, including resonance, of thin plate/shell laminated structure with integrated piezoelectric layers, acting as sensor and actuator based on shear deformation theory. Vibration control of composite beam with surface bonded piezoelectric material had been studied by Crawley and de Luis [7]. Tzou and Tseng [8] presented a finite element formulation for plates and shells containing integrated distributed piezoelectric sensor and actuator applied to control advanced structure. S.Y.Wang [1] presented a finite element model for the static and dynamic analysis of piezoelectric bimorph.

The aim of present work is to simulate active control of forced vibration in composite cantilever beam using piezoelectric material and study the basic behind analysis.

2. Piezo Bimorph Analysys

Fig. 1 shows the geometry of a piezoelectric bimorph. The bimorph structure undergoing the action of the external mechanical and electric forces (a uniformly distributed surface load Ps and an applied electric voltage of V0) is assumed to be perfectly bonded, elastic and orthotropic in behavior with small strains and displacements [1]. The deformation of the bimorph is assumed to take place under isothermal conditions. Moreover, the piezoelectric sensors/actuators are made of homogenous and isotropic dielectric materials and high electric fields and cyclic fields are not involved Based on these assumptions, a linear constitutive relationship [1] is employed for the static and dynamic analysis of the piezoelectric bimorph.

2.1. Linear Piezoelectric Constitutive Equations

Consider a plate having length L and thickness h.

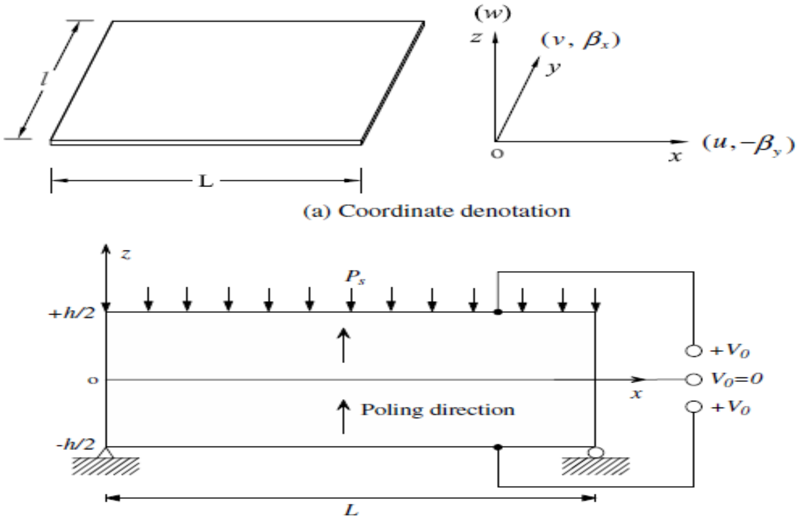

Fig2.1. *Geometry of piezoelectric bimorph*

As per piezoelectric converse and direct effect the linear piezoelectric constitutive equations are expressed as

σ=cε–etE

D=eε+gE

The magnetically static electric field vector E in the linear piezoelectric constitutive equation is related to electric potential field ø by using a gradient vector Δ as

E = -Δø

2.2. Variational Form of Governing Equation

The governing equation of motion of piezoelectric bimorph plate can be derived by using Hamilton's principle, which can be written as [3]

$$\delta\int_{t_1}^{t_2}(T-U+W)dt=0$$

The total kinetic energy for the volume Ω of the bimorph plate is given as

$$T=1/2\int_{\Omega}\dot{u}^{T}\rho\dot{u}d\Omega$$

The total potential energy U, including mechanical strain and electrical potential energy, is given as

$$U=1/2\int_{\Omega}(\sigma^{T}\varepsilon-E^{T}D)d\Omega$$

The total work W done by external mechanical and electrical forces is

$$W=\int_{\Omega}u^{T}p_{b}d\Omega+\int_{\Gamma_s}u^{T}p_{s}d\Gamma_{s}+\sum_{i}u_{i}^{T}p_{i}-\int_{\Gamma_\phi}\phi q_{0}d\Gamma_{\phi}$$

In the governing equation of motion the mechanical displacement field u and electrical potential field ø are unknown functions.

2.2.1. Mechanical Displacement Approximation

According to first order deformation theory, the mechanical displacement of bimorph plate is

u(x,y,z, t)=u0(x,y,t)+zβx(x,y,t)

v(x,y,z,t)=v0(x,y,t)+zβy(x,y,t)

w(x,y,z,t)=w0(x,y,t)

u0,v0,w0 are the component of displacement vector u(x,y,0) at the midplane along the x,y,z axis respectively. u,v,w are the component of displacement vector u(x,y,z) of any point

(x,y,z) in the plane along x,y,z axis respectively; and βx,βy the slopes of the normal to the reference point (x,y,0) on the midplane in the yz,xz plane respectively as shown in the figure 2.1.

$$u = \dot{Z}\, u_0$$

$$\dot{Z} = \begin{bmatrix} 1 & 0 & 0 & z & 0 \\ 0 & 1 & 0 & 0 & z \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

u0= [u0 v0 w0 βx βy]T

For an element the continuous mechanical displacement vector u0 can be approximated by using finite element shape function as

u0= Nu ue

Nu is the matrix of displacement shape function ue is the discrete element nodal displacement vector. Hence the corresponding mechanical displacement at any point can be obtained as

u=Z Nu ue

2.2.2. Electric Displacement Approximation

The electric potential field of each piezoelectric layer are discretised as in to finite sub layers along thickness direction. Fig.3.2 shows that each layer of piezoelectric bimorph is discritised by nsub layer in the thickness to model the actual through the thickness distribution of electrical potential. The electric potential function across the thickness is

øi(Z)= Ni øi

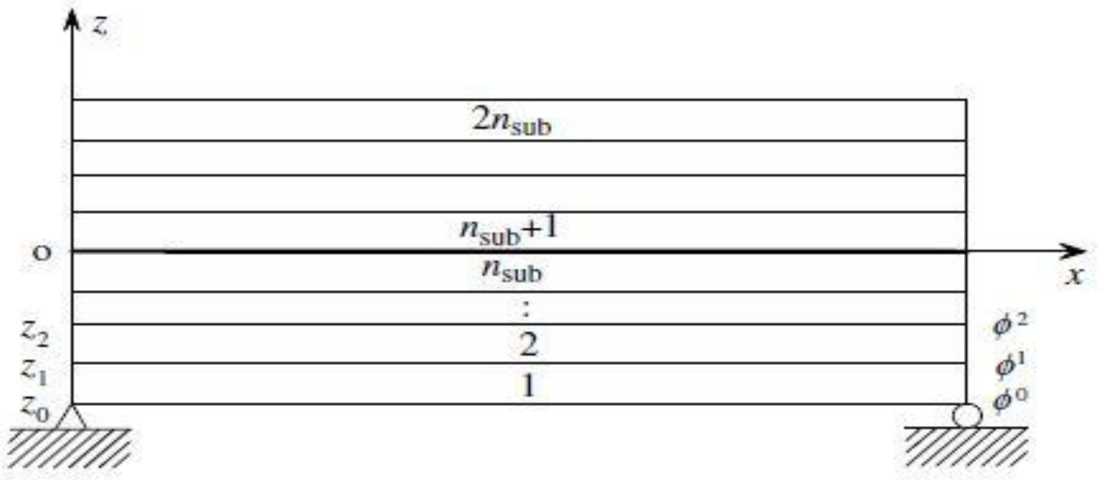

Fig2.2. *Sub layers of piezoelectric bimorph*

Ni is the shape function of electrical potential function and øi is the electrical potential at the top and bottom surfaces of layer.

2.3. Analysis of PVDF Bimorph Beam

The PVDF bimorph piezoelectric beam consists of two piezoelectric layers with opposite polarity. The material properties of piezo beam are shown in Table 3.1. The deflection of bimorph cantilever beam at the specified nodes when a unit voltage (1v) is applied across the thickness of beam are obtained by using Abaqus and verified with standard result [1].

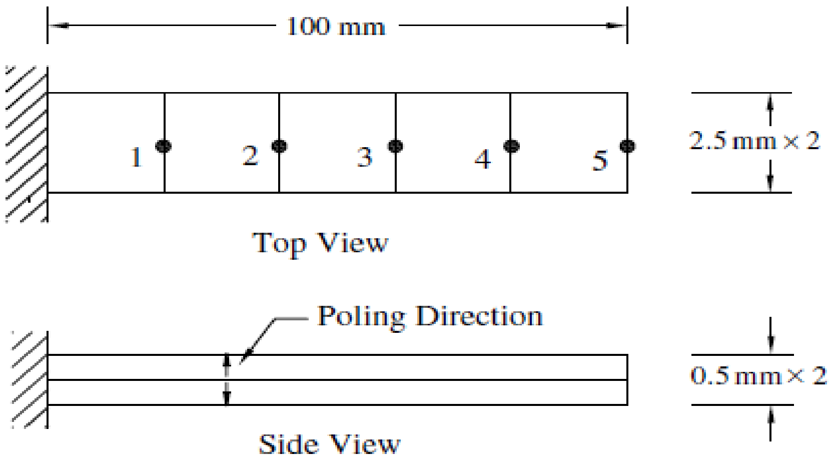

Fig2.3. *A piezoelectric bimorph beam*

The model of piezoelectric cantilever bimorph beam is shown in Fig.2.4.The cubic 18 noded quadratic elements is used for analysis and for meshing the structural meshing type is used. In structural meshing regular shape element is transform in to model shape.

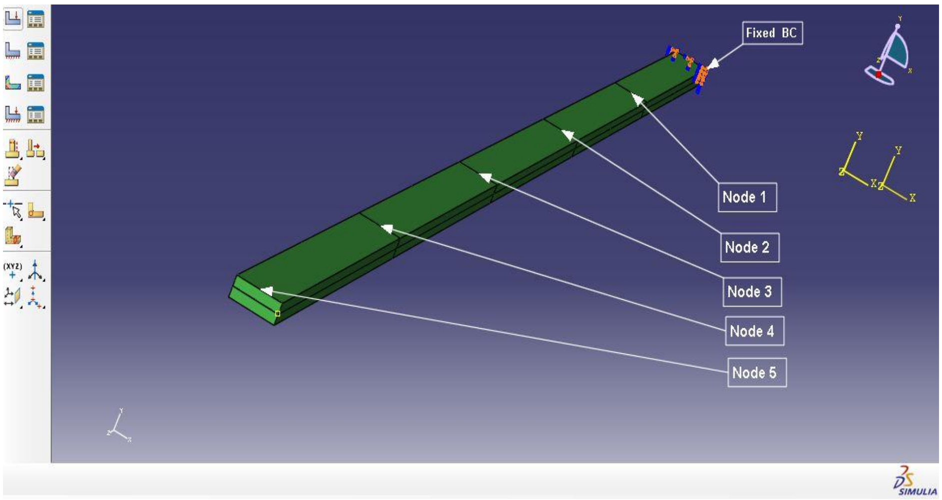

Fig2.4. *Model of piezobimorph beam*

Node	1	2	3	4	5
Theory	0.0138	0.0552	0.124	0.221	0.345
Simulation	0.020	0.102	0.204	0.29	0.357

3. Composite Cantilever Beam Analysys

3.1. Vibration Control of Graphite Epoxy Cantilever Beam Using PVDF

3.1.1. Vibration Control of Graphite Epoxy Cantilever Beam for [$0^0/90^0/90^0/0^0$] Layup Orientation

A cantilever graphite epoxy composite beam is [00/900/900/00] is made up of four layers, equal thickness, symmetric cross-ply and two PVDF layers bonded to the upper and lower surfaces of main structure is considered. The model is shown in Fig.3.1.

The length of beam is taken as 100mm and width is 5 mm. Composite layer thicknesses is 0.125mm and that of piezoelectric layer is 0.25mm. The transverse harmonic load is uniformly distributed over the top surface of cantilever beam which having magnitude q(t) = q sin 2Лft . The magnitude q is taken as 7.5 N/m2 and frequency (f) is taken as 10Hz. For piezoelectric layers the 20 noded piezoelectric brick element is used and meshing is done using structural meshing. For composite beam continuum shell element is used and meshing is done using swept meshing.

The deflection at nodes are shown in Fig.3.1

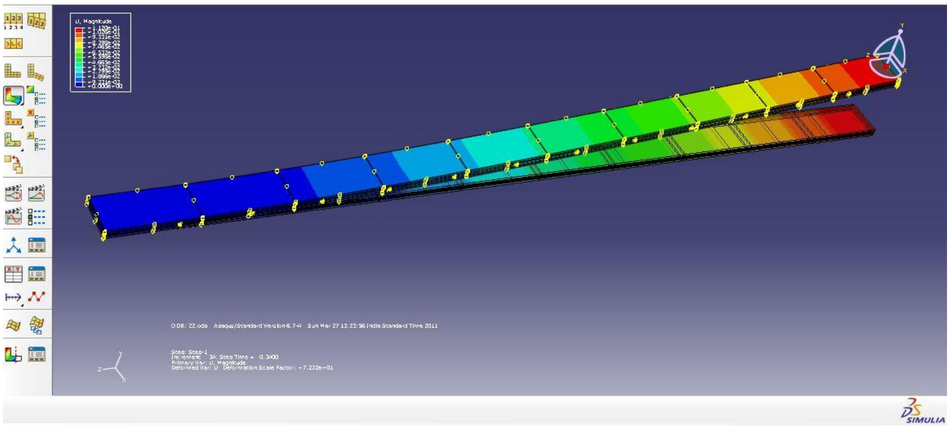

Fig3.1. *Deflection of nodes*

In control part the voltage is sensed from sensor piezoelectric layer (bottom layer). The sensed voltage is magnify by using gain (1x103) and applied to actuator piezoelectric layer (top layer) the controlled and uncontrolled tip deflection of cantilever beam is shown in Fig.3.2 The "g e" represent graphite epoxy.

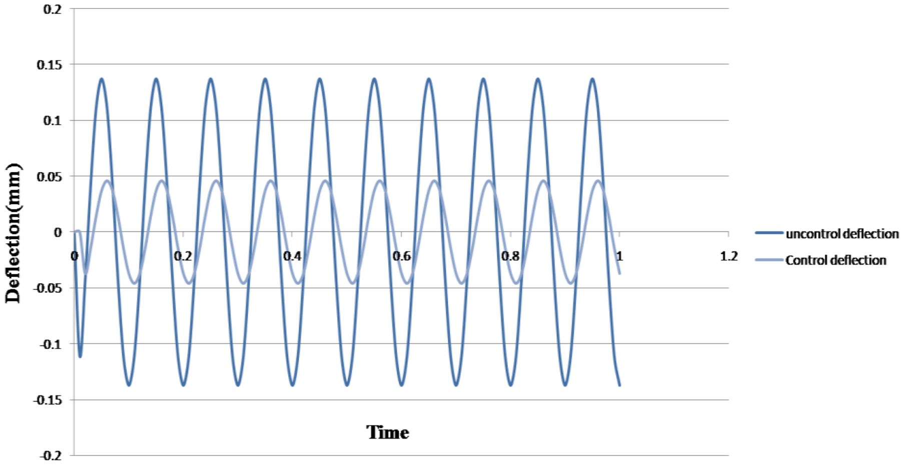

Fig3.2. *Controlled and uncontrolled tip deflection [00/90^0/90^0/00](g e)*

3.1.2. Vibration Control of Graphite Epoxy Cantilever Beam for [00/00/00/00] Layup Orientation

A cantilever graphite epoxy composite beam is [00/00/00/00] is made up of four layers, equal thickness, symmetric cross-ply and two PVDF layers bonded to the upper and lower surfaces of main structure is considered. The beam dimension is taken as mention in section 3.1.1. The model is shown in Fig.3.1. The controlled and uncontrolled tip deflection of cantilever beam is shown in Fig. 5.3

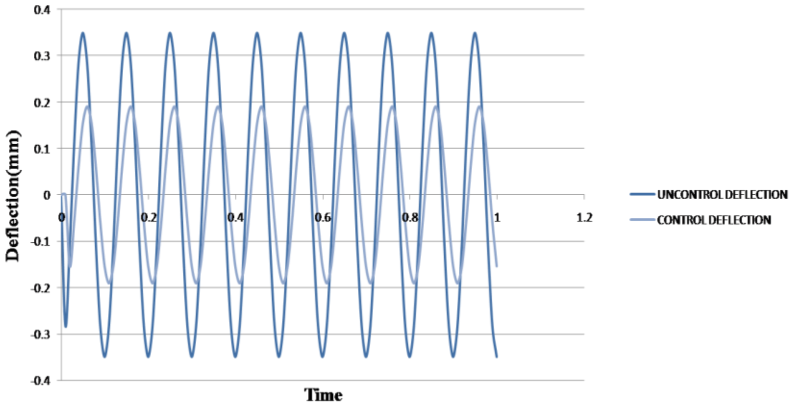

Fig3.3. *Controlled and uncontrolled tip deflection [00/00/00/00] (g e)*

3.1.3. Vibration Control of Graphite Epoxy Cantilever Beam for [00/90^0/0^0/900] Layup Orientation

A cantilever graphite epoxy composite beam is [00/90^0/00/90^0] is made up of four layers, equal thickness, symmetric cross-ply and two PVDF layers bonded to the upper and lower surfaces of main structure is considered. The beam dimension is taken as mention in section 3.1.1. The model is shown in Fig.3.1. The controlled and uncontrolled tip deflection of cantilever beam is shown in Fig. 3.4. In this case the tip deflection is low and the suppression of vibration is more.

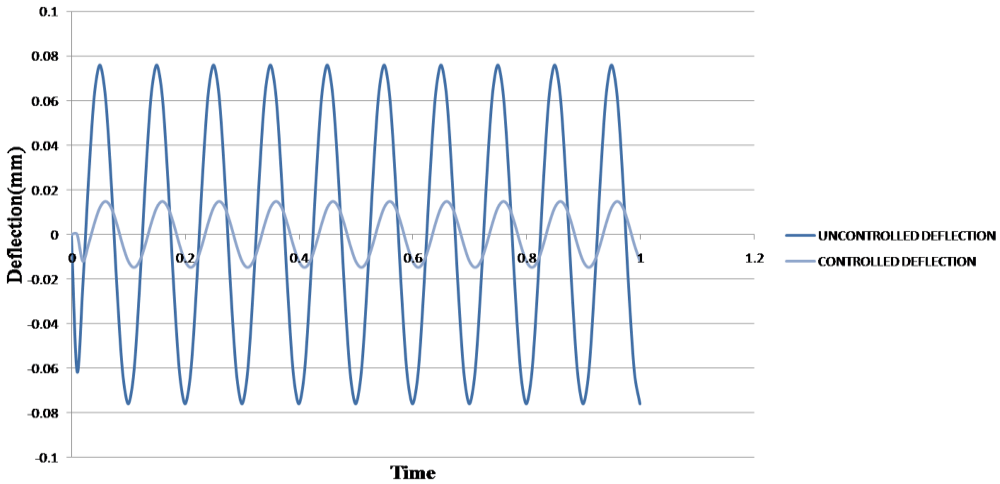

Fig3.4. *Controlled and uncontrolled tip deflection [00/90^0/0^0/90^0] (g e)*

3.2. Vibration Control of Kevlar Epoxy Cantilever Beam Using PVDF

3.2.1. Vibration Control of Kevlar Epoxy Cantilever Beam for [00/90^0/90^0/00] Layup Orientation

A cantilever kevlar epoxy composite beam is [00/90^0/90^0/00] is made up of four layers, equal thickness, symmetric cross-ply and two PVDF layers bonded to the upper and lower surfaces of main structure is considered. The tip deflection is shown in Fig. 3.5. The “k e” represents Kevlar epoxy.

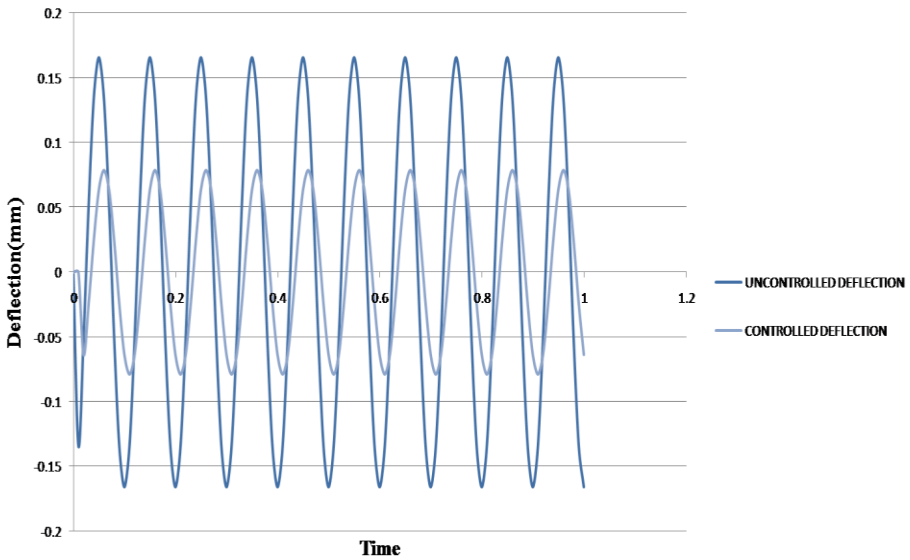

Fig3.5. *Controlled and uncontrolled tip deflection [0^0/90^0/90^0/0^0] (k e)*

3.2.2. Vibration Control of Kevlar Epoxy Cantilever Beam for [00/00/00/00] Layup Orientation

A cantilever kevlar epoxy composite beam is [00/00/00/00] is made up of four layers, equal thickness, symmetric cross-ply and two PVDF layers bonded to the upper and lower surfaces of main structure is considered. The tip deflection of composite cantilever beam is shown in Fig.5.7. In this case deflection is high, the gain is used is same as above case, to more reduce the deflection magnitude the gain is required to increase.

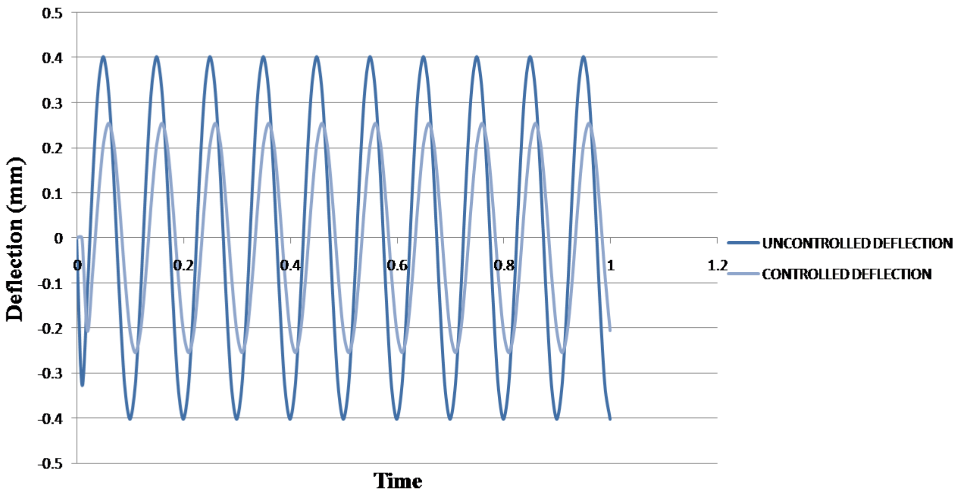

Fig3.6. *Controlled and uncontrolled tip deflection [$0^0/0^0/0^0/0^0$] (k e)*

3.2.3. Vibration Control of Kevlar Epoxy Cantilever Beam for [00/900/00/900] Layup Orientation

A cantilever kevlar epoxy composite beam is [00/900/00/900] is made up of four layers, equal thickness, symmetric cross-ply and two PVDF layers bonded to the upper and lower surfaces of main structure is considered. The tip deflection is shown in Fig.3.7

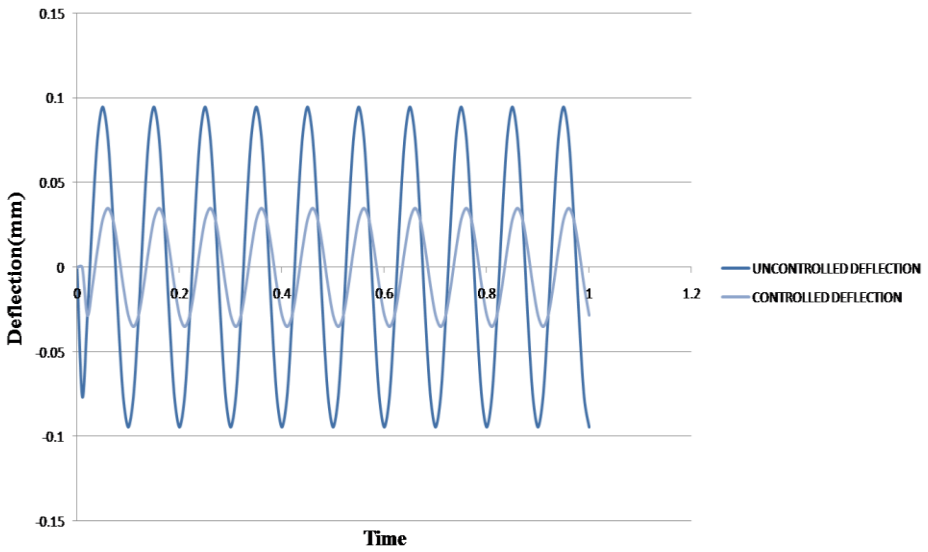

Fig 3.7. *Controlled and uncontrolled tip deflection [$0^0/90^0/0^0/90^0$] (k e)*

4. COMPOSITE SIMPLY SUPPORTED BEAM ANALYSYS

4.1. Vibration Control of Graphite Epoxy Simply Supported Beam for [00/90^0/90^0/00] Layup Orientation

A simply supported graphite epoxy composite beam is [00/90^0/90^0/00] is made up of four layers, equal thickness, symmetric cross-ply and two PVDF layers bonded to the upper and lower surfaces of main structure is considered. In all cases the dimension of beam, loading, is same as used in chapter 3. The deflection of middle node is shown in Fig.4.1.

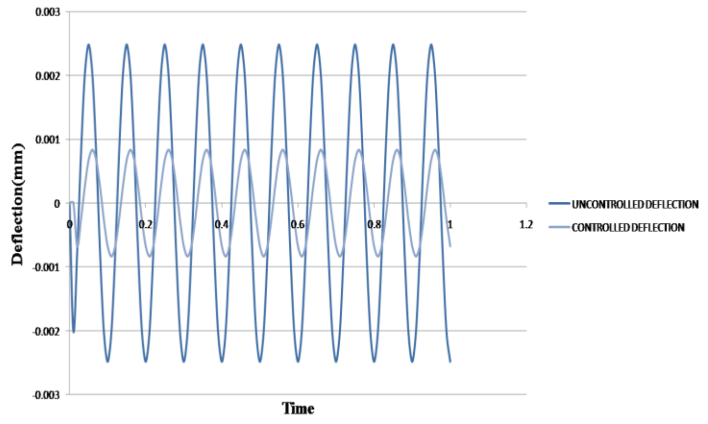

Fig 4.1. *Controlled and uncontrolled Centre node deflection [$0^0/90^0/90^0/0^0$] (g e)*

4.2. Vibration Control of Graphite Epoxy Simply Supported Beam for [00/00/00/00] Layup Orientation:

In this case a simply supported beam having [00/00/00/00] orientation is considered. The deflection of middle node where deflection is large is shown in Fig. 4.2

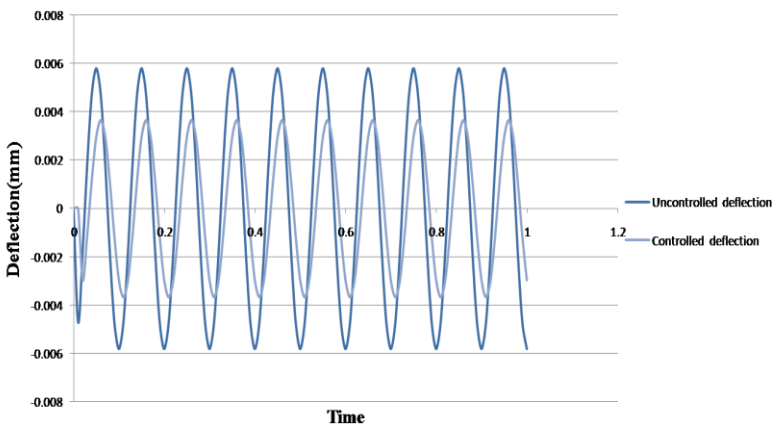

Fig4.2. *Controlled and uncontrolled center node deflection [00/00/00/00] (g e)*

4.3. Vibration Control of Graphite Epoxy Simply Supported Beam for [00/900/00/900] Layup Orientation:

A [$00/90^0/00/90^0$] layup orientation simply supported beam is consider. The deflection of middle node is shown in Fig. 4.3. In this layup orientation the deflection is less so the control deflection is more decreases.

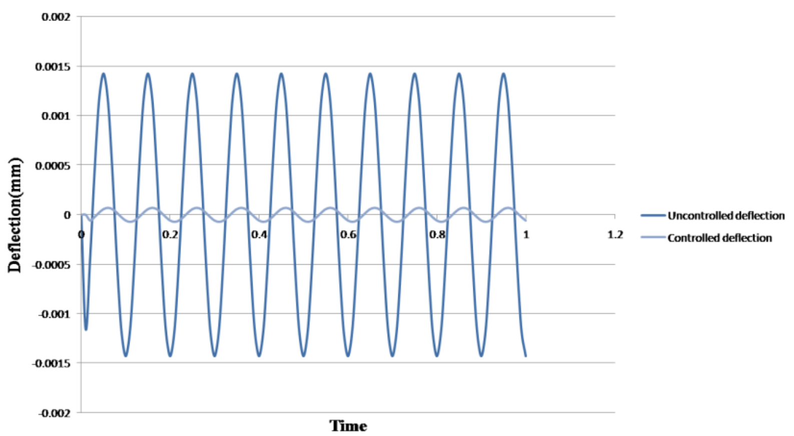

Fig 4.3. *Controlled and uncontrolled Centre node deflection [$00/90^0/00/90^0$] (g e)*

4.4. Vibration Control of Kevlar Epoxy Simply Supported Beam Using PVDF

4.4.1. Vibration Control of Kevlar Epoxy Simply Supported Beam for [00/900/900/00] Layup Orientation

A simply supported beam having [00/90^0/90^0/00] composite orientation is considered. The composite is symmetric and equal thickness. The deflection of middle node is shown in Fig.4.4

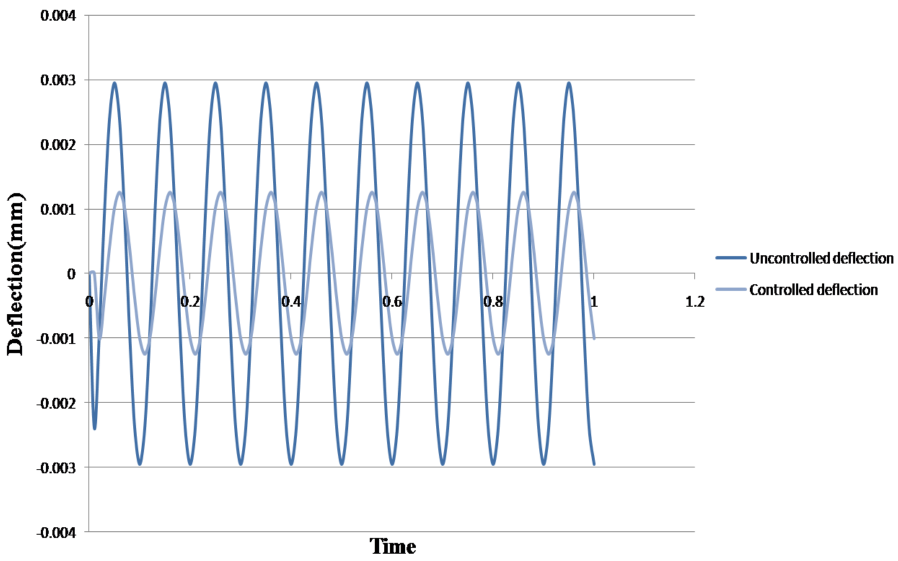

Fig 4.4. *Controlled and uncontrolled middle node deflection [0^0/90^0/90^0/0^0] (k e)*

4.4.2. Vibration Control of Kevlar Epoxy Simply Supported Beam for [00/00/00/00] Layup Orientation

In this case the composite beam having orientation [00/00/00/00] is considered. The deflection of middle node is shown in Fig.4.5. In this case the deflection of beam is more; the gain is used as same in other cases (1x 103). To reduce the control deflection the applied voltage is required to increase.

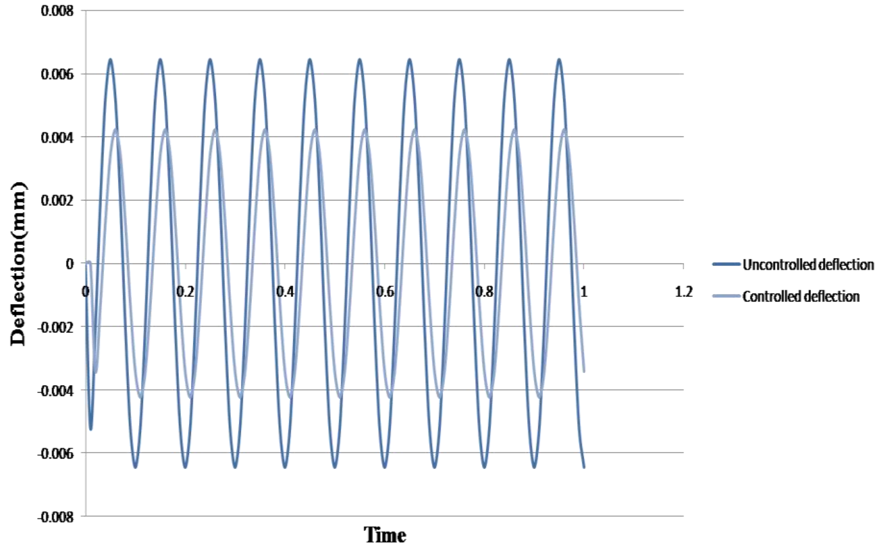

Fig4.5. *Controlled and uncontrolled middle node deflection [00/00/00/00] (k e)*

4.4.3. Vibration Control of Kevlar Epoxy Simply Supported Beam for [00/90^0/00/90^0] Layup Orientation

In this case a simply supported graphite epoxy composite beam is [00/90^0/00/90^0] is made up of four layers, equal thickness, symmetric cross-ply and two PVDF layers bonded to the upper and lower surfaces of main structure is considered. The node deflection is shown in Fig. 4.6

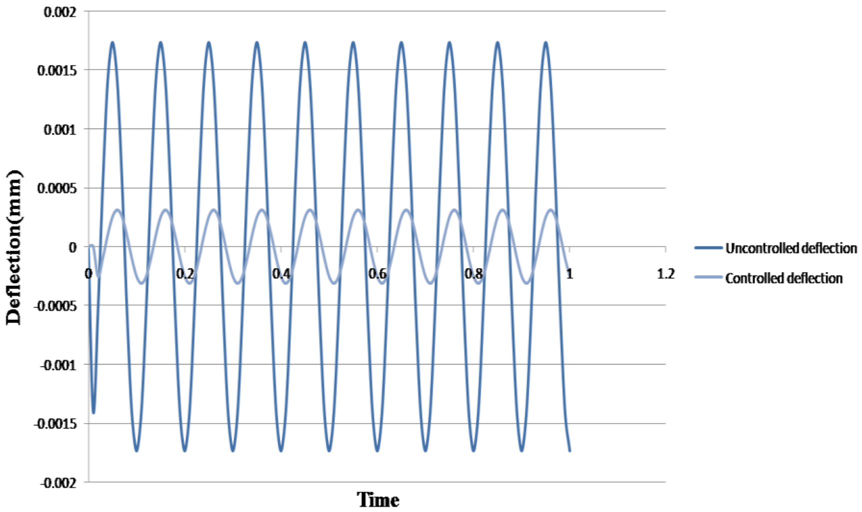

Fig4.6. *Controlled and uncontrolled Centre node deflection [00/90^0/00/90^0] (k e)*

5. Conclusion

The simulation of active control of forced vibration in composite cantilever beam is done using Abaqus 6.7 FEM tool and the result is validate with standard paper. To study the piezoelectric modeling the piezoelectric bimorph analysis is done and theoretical result approximate matches with numerical result. For analysis of composite beam the continuum shell element is used which is based on first order shear deformation theory. The displacement verses time plot for controlled and uncontrolled part of different boundary condition and composite material is evaluated.

References

[1] S.Y.Wang,(2004), A finite element model for the static and dynamic analysis of a piezoelectric bimorph International Journal of Solids and Structures 41 (2004) 4075–4096

[2] Zhi-cheng Qiu_, Xian-min Zhang, Hong-xin Wu, Hong-hua Zhang, “Optimum placement and active vibration control for piezoelectric smart flexible cantilever plate,” Journal of Sound and Vibration 301 (2007) 521–543.

[3] Jose´ M. Simo˜ es Moita a, Cristo´va˜o M. Mota Soares, Carlos A. Mota, “Active control of forced vibrations in adaptive structures using a higher order model. Composite Structures 71 (2005) 349–355.

[4] Bohua Sun, Da Huang, “Vibration suppression of composite laminated beam with a piezoelectric damping layer.,” Composite structure 53 (2001) 437-447.

[5] J.N.Reddy, “Mechanics of laminated composite plates and shells, theory and analysis.

[6] C.M.A. Vasques, J. Dias Rodrigues, Active vibration control of smart piezoelectric beams: Comparison of classical and optimal feedback control strategies Computers and Structures 84 (2006) 1402–1414.

[7] Crawley EF, de Luis J. Use of piezoelectric actuators as elements of intelligent structures. AAIA J 1987; 25(10):1373–85.

[8] Tzou HS, Tseng CI. Distributed piezoelectric sensor/actuator design for dynamic measurement/control of distributed parametric systems: a piezoelectric finite element approach. J Sound Vib 1990;138:17–34.

[9] Chen C-Q, Shen Y-P. Optimal control of active structures with piezoelectric modal sensors and actuators. Smart Mater Struct 1997;8(4):403–9.

[10] Tiersten HF. Linear piezoelectric plate vibrations. New York: Plenum Press; 1969

[11] Tzou HS, Gadra M. Theoretical analysis of a multi layered thin shell coupled with piezoelectric shell actuators for distributed vibration control. J sound vib 1986; 132:433-50

[12] Y. Li, J. Onoda, K. Minesugi, Simultaneous optimization of piezoelectric actuator placement and feedback for vibration suppression,IAA ACTA Astronautic Journal 50 (2002) 335–341.

[13] J.A. Rule, R.E. Richard, R.L. Clark, Design of an aero elastic delta wing model for active flutter control, Journal of Guidance Control and Dynamics 24 (2001) 918–924.