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Static Analysis of Smart Pizolaminated Plate using Finite Element Method

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ABSTRACT

The study of embedded or surface-mounted piezoelectric materials in structures with feedback control has received considerable attention in recent years. One reason for this is that it may be possible to create certain types of structures and systems capable of adapting to or correcting for changing operating conditions without any human effort. The system in itself will be capable to respond the undesired activities in the system so that the bad effect such as excessive deflections, vibration and noise generated in the system can either be eliminated or reduced up to the maximum possible extent. These types of mechanisms are referred to as strain sensing and actuating.

In this present study a finite element formulation has been developed for smart piezolaminated composite plates based on first order shear deformation theory. The linear static analysis of smart piezolaminated composite plates has been done during this work with the use of developed computer code and results obtained from computer code are validated with commercially available software for the purpose.

Key words:Smart Structures, Composite, Plate, Finite Element Method, Piezoelectric material, Actuator, Sensor.

I INTRODUCTION

The use of composite materials in structural components are increasing due to their attractive properties such as high stiffness-to-weight and strength-to-weight ratios, improved wear resistance, creep resistance and ability to tailor the structural properties. Due to inherent in homogeneity and anisotropy involved, the accurate analysis required to design structural parts made up of laminated composites in mechanical, naval, aeronautical and aerospace as well as civil constructions, is a complex task. Composite plates are one of the most widely used structural elements in the aerospace, military and automotive industries etc. H.F. Tiersten[1**]** has investigated the various elastic, piezoelectric and dielectric constants effect. Chao and Lee[2]were designing a guide for the eccentrically stiffened laminates and studied the dynamic analysis for that. Natural frequencies were obtained in the course of simultaneous solution of equations of motion of the plate segments and the related displacement compatibilities.Using an energy principle the equations of motion of the theory were developed. The formulation was based on linear piezoelectricity and includes the coupling between mechanical deformations and the charge equations of electrostatics. B. Samanta et al. [4] developed a generalized finite element formulation for active control of a laminated plate embedded with piezoelectric polymer layers. Higher order shear deformation theory was used with an eight noded two dimensional quadratic quadrilateral isoparametric element. A (0/90/0) lamina sequence was used for the substrate layer and polyvlnylidene fluoride was used for the sensors and actuator layers. They found that significant reduction in amplitude of vibration occurs because of increased damping through feedback.J.N.Reddy [5]develop finite element formulation based on the classical and shear deformation plate theories for the analysis of laminated composite plates with integrated sensors and actuators and subjected to both mechanical and electrical loadings. C.Chee et al.[6] conducted theoretical formulation for modelling composite smart structure. Mathematical model is based on higher order displacement field coupled with a layerwise linear electric potential. Actuation capabilities of the structure due to varying parameters of the piezoelectric.

II THEORETICAL FORMULATION

In formulating the theory for smart plates, FSDT is used to find the linear strain displacement relations of smart plate, of the form given by equation (3.3) constitutive relations, for an orthotropic material given by equation (3.5) and displacement field, given by equation (3.1) accommodating the linear variation of transverse shear strains and hence shear stresses, are considered and linear strain. Here in formulating the theory, we make certain assumptions or place restrictions which are as follows.

BASIC ASSUMPTIONS OF SMART PLATE

Some of the important assumptions used herein are as follows.

- Material properties of each layer in its fibre axis system are prescribed instead of individual fibre andmatrixproperties; i.e., the micromechanics of the layersis not included in the formulation.
- Based on unidirectional fibre orientation, the individual lamina is considered homogeneous and orthotropic, i.e., having three principal planes of symmetry.Individual plies are perfectly bonded together to form the laminates.
- The plies and the laminate are of uniform thickness.
- The middle plane of the laminate is considered as the reference plane and also

III FIRST-ORDER SHEAR DEFORMATION THEORY

The present first- order shear deformation theory has been used in present thesis. This theory yields a constant value of transverse shear strain through the thickness of the smart plate, and thus requires shear correction factors. The shear correction factors are dimensionless quantities introduced to account for the discrepancy between the constant states of shear strains in FSDT. For composite laminates, the shear correction factors, in general, depend on the constituent ply properties, lamination scheme, and type of structure (i.e., geometry and boundary conditions). As already mentioned, the objective has been to find an optimal choice between accuracy and complexity. Hence, first- order shear deformation theory of continuity requirement would make the next set of formulation.

3.1 SMART PLATE GEOMETRIC AND CONSTITUTIVE RELATIONS

The spatial displacement variables for the smart laminated plate are expressed according to first order shear deformation theory.

$$u(x,y,z,t) = u_o(x,y,t) + z\theta_x(x,y,t)$$

$$v(x,y,z,t) = v_o(x,y,t) + z\theta_y(x,y,t) \quad (3.1)$$

$$w(x,y,z,t) = w_o(x,y,t)$$

From this, the spatial displacement field in terms of the reference plane variables, may be written in a compact form as

$$\{\Delta\} = [G]\{d\} \quad (3.2)$$

Where, the spatial and reference plane displacement vectors for the plate are taken as

$$\{\Delta\} = [u \quad v \quad w]^T$$

$$\{d\} = [u_o \quad v_o \quad w_o\theta_x \quad \theta_y]^T$$

Where, $$[G] = \begin{bmatrix} 1 & 0 & 0z & 0 \\ 0 & 1 & 00 & z \\ 0 & 0 & 10 & 0 \end{bmatrix}$$

Now, based on the displacement components in the following non-zero spatial linear strain components can be obtained.

$$\varepsilon_{xx} = u_{,x} = u_{o,x} + z\theta_{x,x} = \bar{\varepsilon}_{xx} + z\bar{k}_{xx}$$

$$\varepsilon_{yy} = v_{,y} = v_{o,y} + z\theta_{y,y} = \bar{\varepsilon}_{yy} + z\bar{k}_{yy}$$

$$\varepsilon_{zz} = w_{,z} = 0$$

$$\gamma_{xy} = u_{,y} + v_{,x} = (u_{o,y} + v_{o,x}) + z(\theta_{x,y} + \theta_{y,x}) \quad (3.3)$$

$$= \bar{\varepsilon}_{xy} + z\bar{k}_{xy}$$

$$\gamma_{xz} = u_{,z} + w_{,x} = \theta_x + w_{,x} = \Phi_x$$

$$\gamma_{yz} = v_{,z} + w_{,y} = \theta_y + w_{,y} = \Phi_y$$

In a smart plate structure, the interaction between the mechanical and electrical fields is defined by Maxwell equations

$$\phi = \frac{1}{2}C_{ijkl}\,\varepsilon_{ij}\,\varepsilon_{kl} - e_{ijk}\,\varepsilon_{ij}\,E_k - \frac{1}{2}p_{kl}E_kE_l \quad (3.4)$$

Such that $\sigma_{ij} = \frac{\partial \phi}{\partial \varepsilon_{ij}}$; $D_i = -\frac{\partial \phi}{\partial E_i}$

Where E is the electric field vector, D is the electric displacement vector, C is the tensor of elasticity module, ε is the strain tensor, σ is the stress tensor, e is the tensor of piezoelectric module, and p is the tensor of dielectric constants, in material axes 1, 2, 3.

We find that the piezoelectric materials have the property to generate electrical charge under mechanical load or deformation, and the reverse, applying an electrical field to the material results in mechanical strains or stresses.

$$\sigma = Q\varepsilon - eE$$

$$D = e^T \varepsilon + pE \quad (3.5)$$

3.2PLATE FINITE ELEMENT DISCRETIZATION

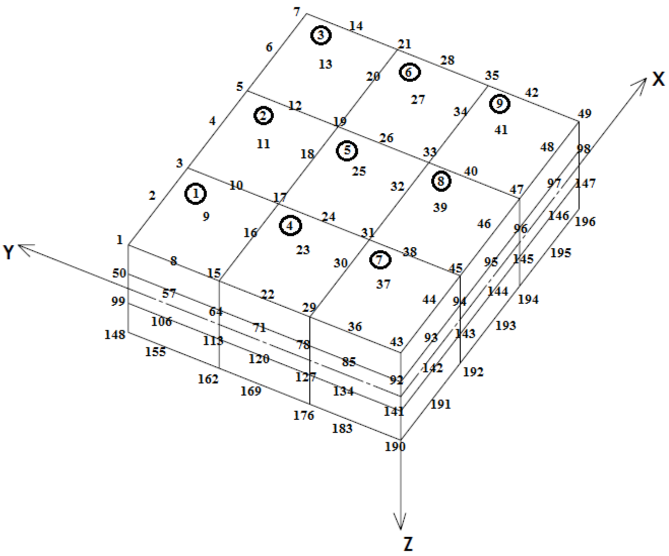


Figure 1: Discretization of plate

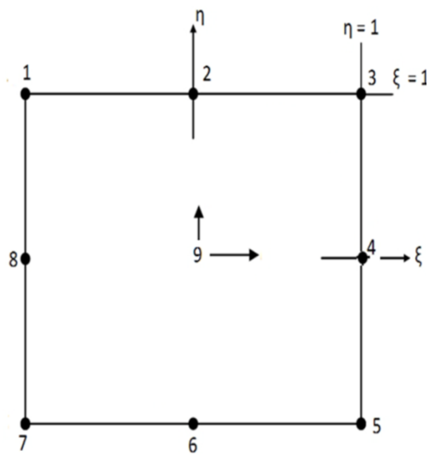


Figure 2 : 9 Noded Element

3.3 STATIC ANALYSIS

We can consider the structure to work in the following manner: first the smart plate structure is exposed to an external applied mechanical load and deforms, corresponding to the deformation, generalized displacements and induced potentials in the sensors. For the static case

$$\left\{[K_{uu_P} + K_{uu_S}] - [K_{u\phi}{}^S][K_{\phi\phi}{}^S]^{-1}[K_{\phi u}{}^S]\right\}\{d^{mec}\} = \{F_{ext}(t)\} \qquad (3.6)$$

The control is introduced through imposed electric potentials in the actuators, which are amplified signals of the sensors

$$\{\phi^{(A)}\} = -G\left[K_{\phi\phi}{}^{(S)}\right]^{-1}\left[K_{\phi u}{}^{(S)}\right]\{d\} \qquad (3.7)$$

Where G is the gain of the amplifier. The actuating voltages of the actuators produce an electric force $\{F^{(A)}\} = \{-K_{u\phi}{}^{(A)}\phi^{(A)}\}$, which will be external mechanical force resulting generalized displacements $\{q^{act}\}$given by

$$\left(\left[K_{uu_P}\right] + \left[K_{uu_S}\right] - \left[K_{u\phi}{}^{(S)}\right]\left[K_{\phi\phi}{}^{(S)}\right]^{-1}\left[K_{\phi u}{}^{(S)}\right]\right)\{d^{act}\} =$$

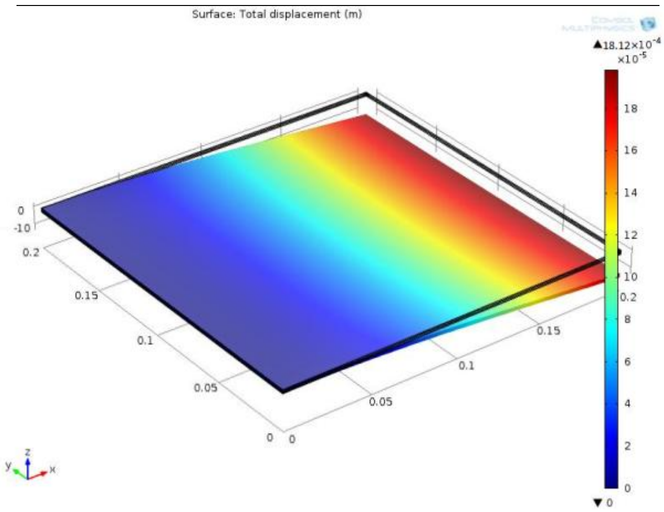
$$-G\left(\left[K_{\phi\phi}{}^{(S)}\right]^{-1}\left[K_{\phi u}{}^{(s)}\right]\{d^{mec}\}\right) \qquad (3.8)$$

The final generalized displacements are finally given by

$$\{d\} = \{d^{mec}\} + \{d^{act}\}.$$

IV RESULT & DISCUSSION

Deflection of smartplate along center line for varying mesh sizes



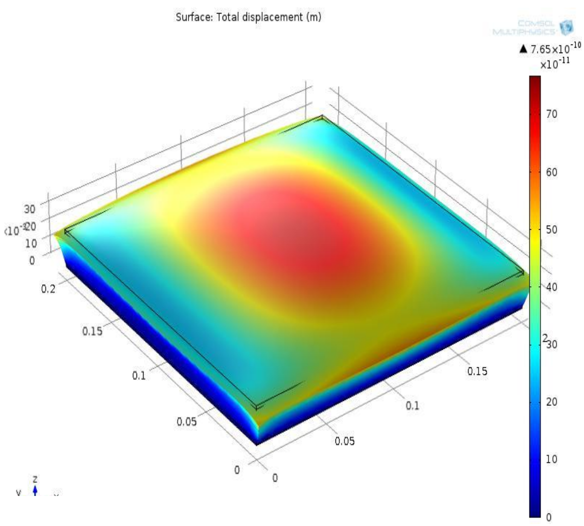
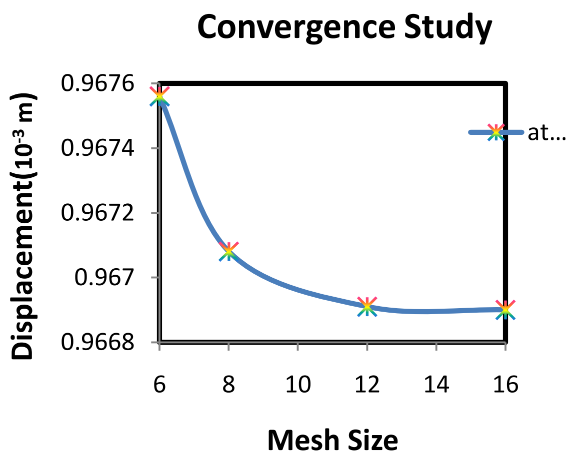


Figure 3: Deflection of smart plate along cenrer line



Response of smart plate after potential

The plate has been analyzed with different mesh sizes and it has been found that the (16 ×16) mesh size gives better result compared with previous. It has been observed from the computed values in above table that for the mesh size (16 × 16) the solution is converging

V CONCLUSION

In the present work, static analyses of smart composite plates have been performed using finite element method. For this purpose, relevant formulation has been derived and a commercial Software COMSOL has been used for study on static response of smart plates.

Following conclusions can be made from the present study:

The deflection of smart piezolaminated plate decreases.The effect of piezoelectric layer controls and reduces the deflection around 50 percent for all edges simple supported plate and clamped, for the cases considered.It can be concluded that due to the piezoelectric properties of laminated plate, deflection decreases considerably.

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