Optimal Location of Piezoelectric Patch on Composite Structure using Viewing Method

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Abstract: A useful material which is manufactured by mixing of two or three different materials in homogeneous level is termed as composite material. In now day’s composite materials are used in wide area such as aerospace, automobiles, satellite, bullet proof jackets, rotor blades etc. In this paper modal analysis of composite material, mixture of polyester as matrix and glass as fiber, is carried out by using ABAQUS software. The modal analysis of composite material for fiber orientation 45° is carried out. In this paper by viewing the different mode shapes of the composite material, the optimal location of piezoelectric patch is carried out.

Keywords: composite structure, modal analysis, fiber orientation, piezoelectric patch, optimal location

1. INTRODUCTION

Composite materials are formed by combining two or more different materials in homogeneous level that have quite different properties. The different materials work together to give a useful composite material of unique properties, but within the composite anyone can easily tell the different materials apart because they do not dissolve or blend into each other. Some of the properties that can be enhanced by forming composite material are fatigue life, corrosion resistant, strength, stiffness, wear resistant, weight, thermal insulation, temperature dependent behavior, attractiveness, thermal conductivity, acoustical insulation [1]. But naturally all these properties are not improved at the same time because some properties are conflict to each other such as thermal insulation and thermal conductivity.

Industrial and commercial applications of composite materials are so vast that it’s impossible to list all of them. So some of the structural applications which includes aircrafts, aerospace, sporting goods, marine, electronics (printed circuit boards), furniture (chair spring), medical industries (bone plates) and many more [2].

Analytical and finite element method is used to solve the different problems under different loads and boundary conditions. FEM modeling can done using different software such as
ANSYS, MATLAB, ABAQUS [11] etc. Modal analysis of any composite materials always results in three parameters that are natural frequencies, mode shapes and damping factor [12].

Composite materials are also used for vibration control [5] because of having distinct properties from normal materials. Analytical and FEM modeling of composite material with piezoelectric patch [12] is used to find out the variation in deflection when it will be stretched and pressed. Modal analysis of composite materials for different fiber orientations is used to analysis the effect of fiber orientation on different properties. Optimal location of piezoelectric patch on composite structures set to be on a position where it will present proper detection and should not coincide with nodes of that mode shape [12]. In this paper by viewing the mode shapes of the composite beams the desired location of piezoelectric patch is carried out.

2. FINITE ELEMENT MODELLING OF COMPOSITE MATERIAL

In this section the finite element modeling of composite material as well as modal analysis is carried out by using ABAQUS software.

2.1 Modeling of composite material in ABAQUS software

Composite material mainly consists of two phases that is matrix phase and fiber phase. The matrix plays an important role to keep the fibers at desired positions. The desired distribution of the fibers is very important from micromechanical point of view. Mainly the function of fibers is to carry load and to provide high strength to the composite material, different fiber orientations results in different strength or enhancing different properties. In this paper, as shown in Fig.1, fiber orientation 45° is selected because it helps to resist shear of the composite beam. Properties of Glass-Polyester Composite Beam [3] are $E_1=37.41\text{GPa}$ $E_2=13.67\text{GPa}$ $G_{12}=5.478\text{GPa}$ $G_{13}=6.03\text{GPa}$ $G_{23}=6.666\text{GPa}$ $\nu_{12}=0.3$ $\rho=1768.9\text{Kg/m}^3$. The dimensions of beam are $L_x=0.11179\text{m}$ $L_y=12.7\times10^{-3}\text{m}$ and $L_z = 3.38\times10^{-3}\text{m}$ and mesh size is 10×1.

![Fig.1 Shows modeling of composite beam in ABAQUS software as front and top view of matrix and fibers.](image-url)
2.2 Modal analysis of composite material

In this section modal analysis of composite material is carried out. Before proposing viewing method, results of modal analysis are validated with [3] using ABAQUS software. Well satisfying results comes out with percentage error of 0.5%. In modal analysis four mode shapes are considered in which there is no node formation for 1st mode shape but for 2nd mode shape there is one node, for 3rd mode shape there is two nodes similarly for 4th mode shape there are three nodes.

Table i. Describes natural frequencies (in Hz) of Glass Polyester composite beam having fibers angle at 45° under the boundary conditions of clamped –free.

| Mode No. | Present | Reference [3] | Mode Shapes |
|----------|---------|----------------|-------------|
| 1.       | 121.11  | 120.5          |             |
| 2.       | 773.35  | 752.4          |             |
| 3.       | 2251.8  | 2092.9         |             |
| 4.       | 4687.3  | 4062.2         |             |

3 FEM OF COMPOSITE MATERIAL WITH PIEZOELECTRIC PATCH

Finite element modeling of composite material having piezoelectric patch at five different locations is carried out using ABAQUS software.
3.1 Modeling

Properties and dimensions of piezoelectric patch [13] are $E_{31} = -8.9678$, $E_{32} = 8.9678$, $E = 23.3$ GPa, $\rho = 7800$ Kg/m$^3$, $\varepsilon = 0.34$, Dielectric constant $= 6.6075 \times 10^{-9}$, dimensions of piezoelectric patch are $L_x = 0.011179$ m, $L_y = 0.0127$ m and $L_z = 0.0005$ m and mesh size $2 \times 2$.

![Diagram of piezoelectric patch](image)

(a) Top View

(b) Front View

Fig. 2 Different locations for piezoelectric patch on beam represented as L1, L2, L3, L4 and L5 (a) top view (b) front view

3.2 Modal analysis of composite material with piezoelectric patch at different locations.

Table II. Describes Natural frequencies (in Hz) for different locations of piezoelectric patch on composite beam having fiber orientation $45^0$.
4. OPTIMAL LOCATION OF PIEZOELECTRIC PATCH USING MODAL ANALYSIS

In Table ii first column represents the different locations of the piezoelectric patch on composite beam as L1, L2, L3, L4 and L5. For each position of piezoelectric patch four mode shapes were analyzed as shown in second column with particular frequencies. At L1 location for 4th mode shape there are three nodes out which 3rd node is coincide with the location of piezoelectric patch due to which the deflection won’t be detected hence this position can’t be set as optimal location. Similarly for location L2, L3 and L4, nodes are coinciding with piezoelectric patch for mode shapes 2nd, 3rd, 4th respectively, so these locations are not considered as an optimal location but at L5 location by viewing all the mode shapes it is clear that there is no nodes which are coincide with this location so L5 is the optimal location for piezoelectric patch. Although by comparing 1st mode shapes for all the locations it is analyzed
that natural frequency goes on increasing with decrease in the distance of patch from fixed boundary condition [12].

5. CONCLUSION

In this paper, the choice of optimal location of piezoelectric patch on composite beam is proposed using the modal analysis. The natural frequencies and mode shapes of the composite beam are find out using ABAQUS software. By viewing the mode shapes, the optimal location of piezoelectric patch is estimated. The estimated location is near the boundary of the cantilever beam. To validate this in this paper the piezoelectric patch is shifted at different location on the cantilever beam. It is seen that when the piezoelectric patch is located at the tip of the cantilever beam less strain produced in the patch. The effect is there is less change in the overall natural frequency of the system. When the piezoelectric patch is near the boundary of cantilever beam the natural frequency of the overall system is increased. It means the piezoelectric patch adds stiffness to the composite beam.

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REFERENCES

[1] R. M. Jones, “Mechanics of composite material,” 2nd ED, Taylor and Francis, Philadelphia, 1999.
[2] E. J. Barbero, “Finite element analysis using ABAQUS,” Taylor and Francis, Boca Raton, 2013.
[3] L. Jun, H. Hongxing and S. Rongying, “Dynamic finite element method for generally laminated composite beams,” International Journal of Mechanical Sciences, vol.50, pp. 466–480, September 2008.
[4] Y. Teboub and R. Hajela, “Free vibration of generally layered composite beams using symbolic computations,” Composite structures, Elsevier Science Limited 33, pp. 123-1340, 1995.
[5] S. R. Marur and T. Kant, “Free vibration analysis of fiber reinforced composite beams using higher order theories and finite element modeling,” Journal of Sound and Vibration, vol. 194(3), pp. 337-351, 1996.
[6] A. A. Khdeir and Reddy J. N, “Free vibration of cross-ply laminated beams with arbitrary boundary conditions,” International Journal of Engineering Science, vol. 32, pp. 1971–80, 1994.
[7] S. Ganesh, K. S. Kumar and P. K. Mahato, “Free Vibration Analysis of Delaminated Composite Plates using Finite Element Method,” Procedia Engineering, vol. 144, pp. 1067 – 1075, 2016.
[8] R. B. Abarcar and P. F. Cunniiff, “The Vibration of Cantilever Beams of Fiber Reinforced Material,” Journal of Composite Materials, vol.6, pp. 504, 1972.
[9] Jaehong. L, “Free vibration analysis of delaminated composite beams,” Computers and Structures, vol. 74, pp. 121-129, 2000.
[10] Ju, F. Lee, H.P and Lee, K.H, “Finite element analysis of free vibration of delaminated composite plates,” Composites engineering, vol. 5, pp. 195-209, 1995.
[11] G. L. C. M. de Abreu, J. F. Ribeiro and V. Steffen, “Finite Element Modeling of a Plate with Localized Piezoelectric Sensors and Actuators,” Journal of the Brazil society of mechanical science and engineering, Journal of the Brazil Society of Mechanical Science and Engineering, vol.26, pp. 117-128, June 2004.
[12] E. L. Oliveira, N. M. M. Maia, R. G. A. da Silva, F.J. Afonso and A. Suleman, “Modal characterization of composite flat plate models using piezoelectric transducers,” Mechanical system and signal processing, vol.79, pp. 16-29, October 2016.
[13] A. K. Bagha and S.V. Modak, “Virtual Sensing of Acoustic Potential Energy Through a Kalman Filter for Active Control of Interior Sound,” Proceedings of the 32nd IMAC, vol. 6, 2014.

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EDUCATION

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RESEARCH INTERESTS

• Vibro-acoustics
• Active noise control
• Experimental Modal Analysis
• Finite element model updating

LIST OF PUBLICATIONS

1. Structural sensing of interior sound for active control of noise in structural-acoustic cavities, Journal of the Acoustical Society of America (JASA), 138 (1), July 2015, 11–21.

2. Feedback Control strategies for Active Structural-Acoustic Control of Interior Noise, Journal of the Acoustical Society of India (JASI), 42 (2), April 2015, 84–94.

3. Virtual Sensing of Acoustic Potential Energy through a Kalman Filter for Active Control of Interior Sound, Proceedings of the 32nd International Modal Analysis Conference (IMAC-XXXII), A Conference and Exposition on Structural Dynamics, Orlando, Florida, USA, 3-6 February, 2014, 221-241.

4. A study on the influence of model uncertainties on the performance of a feedback control based ASAC system, Proceedings of INTER-NOISE 2014, 43rd International Congress on Noise Control Engineering, Melbourne, Australia, 16-19 November 2014.

5. Active structural-acoustic control of interior noise using direct output feedback, Proceedings of the 17th ISME conference on Advances in Mechanical Engineering, held at IIT Delhi, New Delhi, October 3-4, 2015.

6. Active structural-acoustic control of interior noise using direct output feedback- an experimental study, International conference on mechanical and electrical systems (ICMES-2016),held at Hong Kong in 4-6 December 2016.