GEOMETRIC NONLINEAR SHAPE AND VIBRATION CONTROL OF FUNCTIONALLY GRADED SMART STRUCTURES

A Thesis

submitted

by

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Declaration by the Research Scholar

This is to certify that the thesis entitled "**Geometric Nonlinear Shape and Vibration Control of Functionally Graded Smart Structures**" submitted by me to the Indian Institute of Technology Mandi for the award of the degree of Doctor of Philosophy is a bonafide record of research work carried out by me in the School of Engineering, Indian Institute of Technology Mandi, under the supervision of Dr. Rajeev Kumar and Dr. Vishal Singh Chauhan. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

In keeping with the general practice of reporting scientific observation, due acknowledgements have been made wherever the work described is based on the findings of other investigators.

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Thesis Certificate

This is to certify that the thesis entitled "**Geometric Nonlinear Shape and Vibration Control of Functionally Graded Smart Structures**" submitted by Mr. Chander Kant Susheel to the Indian Institute of Technology Mandi for the award of the degree of Doctor of Philosophy is a bonafide record of research work carried out by him under our supervision in the School of Engineering, Indian Institute of Technology Mandi. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

Scientists and engineers, in their quest to improve the performance and safety of aerospace structures, focused their efforts in development of materials which exhibit superior structural capabilities in extreme environments while keeping the weight as low as possible. The aerospace structures, such as space antenna reflectors are exposed to structural vibrations, which could be triggered by satellite repositioning, meteoroid impacts, self-weight at different elevation angles, thermal shock etc. The piezoelectric materials are one of the advanced materials which have been abundantly used in the development of adaptive structures. These smart structures are used to attenuate the vibrations generated in the structures. The space structures such as antenna reflectors are highly nonlinear systems with time-varying structural parameters. Therefore, the vibration control in these structures using conventional controllers is not effective. Also, the use of piezoelectric materials as sensors and actuators for active vibration and shape control have been limited in aerospace applications due to their poor surface bonding capabilities and low reliability. Moreover, structural dissimilarities can cause failure due to cyclic strains. The reliability of the structure can be increased by optimizing the stress distribution across the cross section. To overcome these shortcomings, new type of piezoelectric material commonly known as functionally graded piezoelectric material (FGPM) has attained more attention in recent years.

This research is motivated by the still existing need for actuators and sensors that are more durable than the current. Also, in the area of aerospace engineering, it is necessary to predict the deflections and strains in structures more accurately so that they can be precisely designed. In this research, nonlinear finite element formulation (FEM) is implemented to

determine the static and dynamic response of piezolaminated functionally graded shell structure under coupled thermo-electro-elastic model. The FEM formulation is based on first order shear deformation theory and linear piezoelectric theory. Quadratic distribution of electric field is assumed. A four node shell element with mechanical, electrical and thermal degrees of freedom is used to model the thin piezolaminated functionally graded shell structures. To avoid the shear locking phenomenon, mixed interpolation of transverse tensorial component algorithm is considered. The finite element formulation and developed computer code is validated with existing literature.

Shell structures in the form of plates, cylindrical and spherical panels are widely used in the areas such as aerospace, navigation and the automotive industry, mostly as focusing viewfinders, antennas, solar panel and airfoil structures. In these applications, undesirable shape changes, which occur due to shell flexibility, not only degrade the system performance but also influence the structure's integrity and reliability. In order to overcome these limitations, functionally graded piezoelectric materials have been used for active shape control of different functionally graded structures (plate, cylindrical and spherical) under different natural and essential boundary conditions.

The shell structures are highly nonlinear systems with time varying structural parameters. Hence, the active vibration control of shell structures is not very effective using conventional controllers. A nonlinear fuzzy logic controller is developed for active vibration control application. 49 rules have been established to develop the controller. Input sensor voltage and rate of change of sensor voltage are considered as inputs while actuator voltage is considered as output. To study a smart beam an aluminum beam with surface bonded piezoelectric patches

(PZT-5H) at the root is considered. Experimental results are obtained by using LABVIEW programs developed in the study. It is observed that numerical predictions are well matched with the experimental results. The designed fuzzy logic controller is validated with the experimental results and its performance is compared with conventional controllers both experimentally and numerically. The active vibration control of various plate and shell structures is numerically studied using the FGPM patches. In the view of its practical importance beam shaping and beam steering application of antenna reflector are studied using the FGPM patches. Genetic algorithm is used to determine optimum size and location of piezoelectric patches and voltage applied to patches in order to minimize the error between desired and controlled shape of antenna reflector.

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