

DEVELOPMENT OF AN ADAPTIVE TUBULAR COMPOSITE HOUSING FOR ACTIVE VIBRATION SUPPRESSION AND PRECISION POSITIONING

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ABSTRACT

Adaptive or intelligent structures which have the capability for sensing and responding to their environment promise a novel approach to satisfying the stringent performance requirements of future space missions. Sensors and actuators in combination with composite materials afford lightweight structures with increased structural efficiency and thermal stability, in addition to the ability to monitor and respond to external stimuli to control shape, properties, and dynamic responses of the structure. The main objective of this research is to develop an adaptive composite tubular housing with vibration suppression and precision positioning capabilities for the integration into an active composite strut. This work takes advantage of the basic understanding of science and technology developed by former space grant students Lucy Wong, Grace Leung, Gay Leong, and Reid Takamiya. The active composite tubular housing and strut will later be integrated into a platform system. The applications of the adaptive platform with vibration suppression and precision positioning capabilities include an optical bench or a thruster vector control mount for a satellite. The active composite tubular housing has been tested on ANSYS Finite Element Analysis for both flexural bending and axial vibration suppression.

INTRODUCTION

The emerging science of adaptive or smart/intelligent materials and systems is expected to lead to radically new and novel structures that will have capabilities for sensing and responding to external stimuli imposed upon them. The combination of sensing, actuating, information processing, and feedback/feedforward capabilities yields a total intelligent system with optimized properties, sensing, response, and performance. Space mission payoffs in the use of intelligent structures might include improvement in mission accuracy, equipment redundancy or versatility, maneuverability, reliability, survivability and orbit lifetime. Piezoelectric ceramic materials, such as lead zirconate titanate (PZT), will be utilized in this application as both actuators and sensors. Piezoelectric materials do not require radiation shielding and are fairly insensitive to temperature unlike fiber optics or electrostrictive materials such as lead-magnesium-niobate, (PMN) (Anderson et al., 1990). The inherent rigidity of piezoelectric ceramic materials (PZT's) also leads to a more efficient conversion of electrical to mechanical energy ensuring good actuation capabilities. Furthermore, the piezoelectric coupling between the elastic and dielectric phenomena is a somewhat linear relationship between the mechanical and electrical behavior of the material that simplifies data acquisition and control of the structural response.

Active structures technology is being developed to produce high performance structures that make use of active structural members or active struts to control the elastic motion of the structure at the submicron level (Fanson, et al., 1989). Since the precision positioning requirements for active structures are on the order of microns, little to no vibration due to maneuvering of the spacecraft can be tolerated. As a result, it is desirable for the active struts to possess active vibration suppression capabilities to a) avoid any inaccuracy and malfunctioning

of the device due to the external noises (i.e., sources of vibration) contribute to the overall vibration suppression of the entire platform structure. Active control systems that rely on piezoelectric materials are effective in controlling the vibration of structural elements such as beams, rods and struts. Many of the proposed designs for flexible space structures are truss-type structures. One obvious approach to designing an active structure is to replace certain passive members of the truss structure with piezoelectric or extensible links as well as appropriate joints. The active members or struts can be used as load carrying members as well as actuator/sensor pairs.

As previous work in terms of active struts, e.g., Russell et al. (1999), Dekens and Neat, (1999), O'Brien (1998), Fujita et al., (1998), and Webster et al. (2000) developed active struts with vibration suppression capabilities. Active struts have also been used for vibration suppression to maintain precision positioning rather than a direct precision positioning function. Dr. Nejhad and his former space grant student, Reid Takamiya (2002) employed a precision motor and piezoelectric actuator in series to achieve coarse and fine positioning of the active composite strut with vibration suppression capabilities.

The main objective of this research is to design and develop an active composite tubular housing for use with the active composite strut system. The active tubular composite housing will be tested for lateral and axial vibration suppression capabilities employing finite element modal and harmonic analyses and vibration suppression schemes developed by Ghasemi Nejhad and Russ (2002a, 2002b, 2002c) and Russ and Ghasemi Nejhad (2002).

METHODS

Finite element analysis using ANSYS was conducted for vibration suppression of the Active Composite Tubular Housing. The model used for the analyses had one end of the tubular housing fixed (representing the end next to the bottom joint of an adaptive platform) and the other end free to vibrate (representing the end where the strut is connected to the active composite panel at the top joint).

There were two vibration suppression schemes used to test for vibration analysis, and both were done by assuming that the displacements of the composite tubular housing due to the load only were the same as those obtained by the applied actuator voltage. The first scheme is constant voltage (Ghasemi Nejhad and Russ, 2002a), which finds the best voltage that suppresses all points in the frequency range of interest. The second scheme is corresponding voltage (Ghasemi Nejhad and Russ, 2002b), which uses one voltage value for each frequency to bring the displacements of each point down to zero on the frequency range of interest.

RESULTS AND DISCUSSION

Modal analysis yielded the first two modes of flexural bending (mode 1 at 496 Hz, see Figure 1, and mode 2 at 4055 Hz, see Figure 3), and the first mode of axial vibration for the structure (at 2392 Hz, see Figure 5).

For harmonic analysis of flexure bending, a shear force of ¼ lb, was applied to the free end of the composite tubular housing. Using the constant voltage scheme (Ghasemi Nejhad and Russ, 2002a) for bending mode 1 (496 Hz), a voltage of -577.786 volts will achieve a suppression of 99% (see Figure 2). It should be noted that a similar result is achieved using the corresponding voltage scheme (Ghasemi Nejhad and Russ, 2002b). Moving onto bending mode 2 (4,055 Hz), a constant voltage of -63.321 volts will achieve a suppression of 87% (see Figure 4). With the application of the corresponding voltage scheme, a suppression of 99% was achieved.

For harmonic analysis of the axial vibrations, a pressure of 181,000 Pa, equivalent to a 5-pound force, was applied to the free end of the composite tubular housing. Using the constant

voltage approach for axial mode 1 (2,392 Hz), the best voltage on the interval was found to be 0.221 volts, which in some cases actually increased the displacements (see Figure 6). With the application of the corresponding voltage scheme, a suppression of 99% was achieved.

CONCLUSIONS

Employing the corresponding voltage scheme, vibration suppression of 99% was achieved, whereas the constant voltage scheme did not work in some cases. In comparison to the active composite flat panel, the composite tubular housing has a higher flexural rigidity than the active composite flat panel, and hence it is harder for the actuators to bend it.

The results are promising and lay the groundwork for manufacturing of the active composite tubular housing which will be integrated with the strut system along with the active composite panels to form an adaptive platform. The active composite tubular housing can be used in other applications besides in tilting platforms and will offer great benefits in space applications as well as other precise applications.

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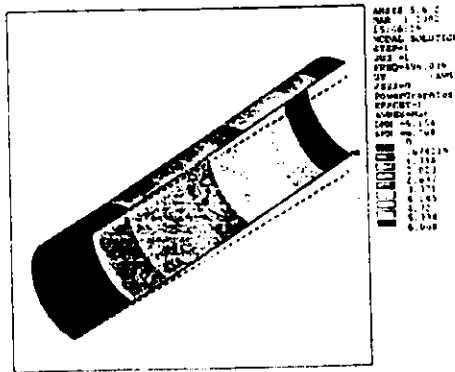


Figure 1: Flexural bending mode shape 1 of the composite tubular housing.

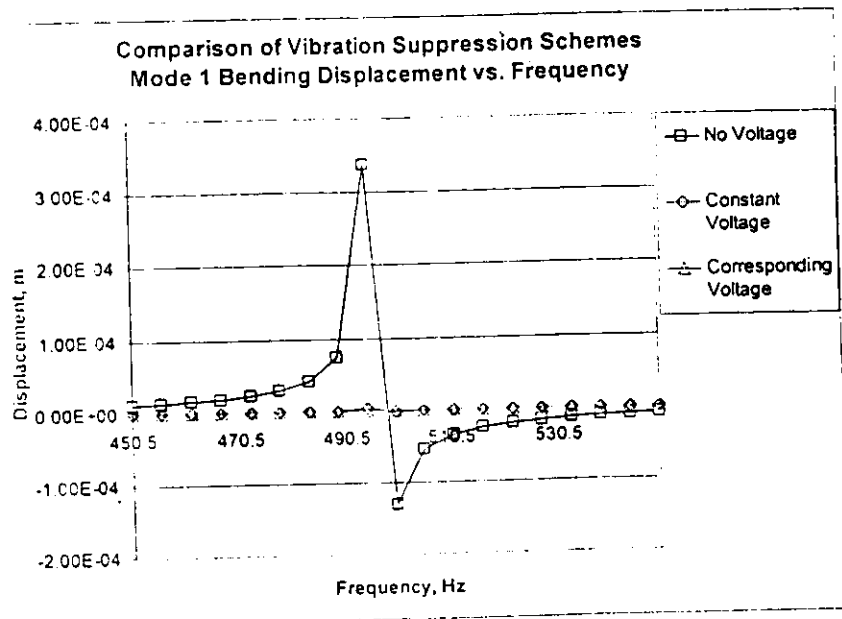


Figure 2: Flexural bending mode 1 active vibration suppression of Figure 1.

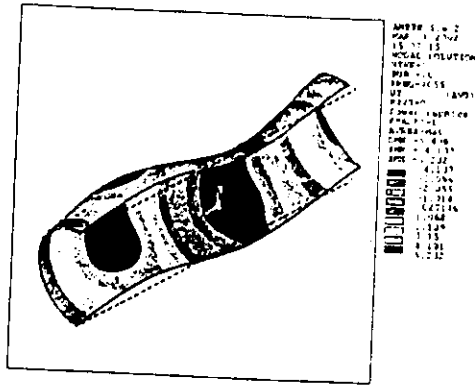


Figure 3: Flexural bending mode shape 2 of the composite tubular housing.

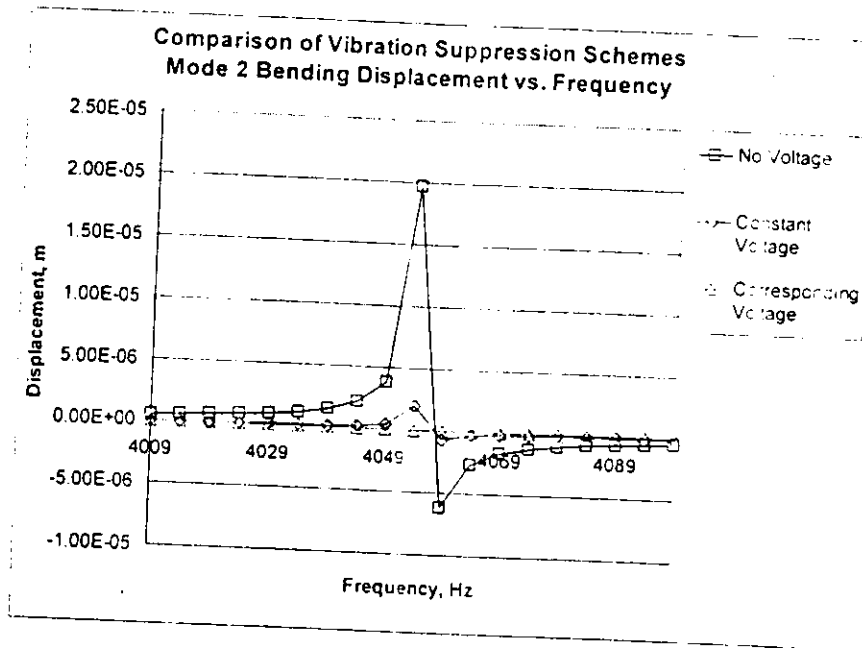


Figure 4: Flexural bending mode 2 active vibration suppression of Figure 3.



Figure 5: Axial vibration mode shape 1 of the composite tubular housing.

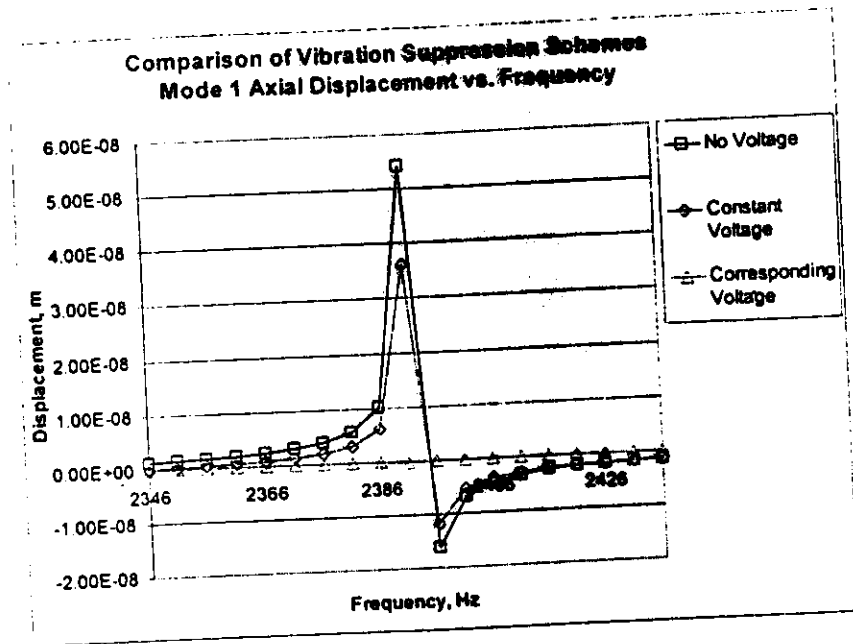


Figure 6: Axial bending mode 1 active vibration suppression of Figure 5.