DESIGN, MANUFACTURE, AND TESTING OF AN ACTIVE COMPOSITE PANEL PROTOTYPE WITH VIBRATION SUPPRESSION AND PRECISION POSITIONING

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ABSTRACT

An Active Composite Platform (ACP) is designed, analyzed, manufactured, and tested for vibration suppression and precision positioning capabilities to be utilized in an experiment. Piezoelectric actuators (piezos) from Active Control eXperts, Inc. (ACX) were surface-mounted onto a composite beam to develop active composites that can perform both vibration suppression and precision positioning. An Active Aluminum Platform (AAP) was designed, analyzed, manufactured and tested first in order to become familiar with the piezos and finite element software, ANSYS. Numerical solutions obtained from ANSYS estimated the maximum deflection of each solid model (AAP and ACP) as well as their vibration suppression capabilities. Upon successful manufacturing, the platforms were tested. The AAP showed a reduction of vibration of 96.27 % and the ACP showed a reduction of vibration of 70.5 %. For a DC input voltage of 80 V, the AAP showed a maximum deflection of 0.348 mm and the ACP showed a maximum deflection of 0.015 mm. The higher stiffness and larger thickness of the composite material when compared to the aluminum material explains the difference in vibratio and positioning capabilities of both platforms.

INTRODUCTION

Adaptive or intelligent materials and systems are expected to lead to radically new and novel structures that will have capabilities for sensing and responding to external stimuli imposed upon them. The use of composite material takes advantage of high strength and stiffness-to-weight ratios combined with the flexibility in tailoring the structure to meet the loading conditions, resulting in greatly increased structural efficiency. Therefore, the combination of sensing, actuating, information processing, and feedback/feedforward capabilities with composite materials yields a total Smart Composite system with optimized properties, sensing, response, and performance. Space mission payoffs in the use of Smart Composite systems include improvement in mission accuracy, equipment redundancy or versatility, maneuverability, reliability, survivability and orbit lifetime.

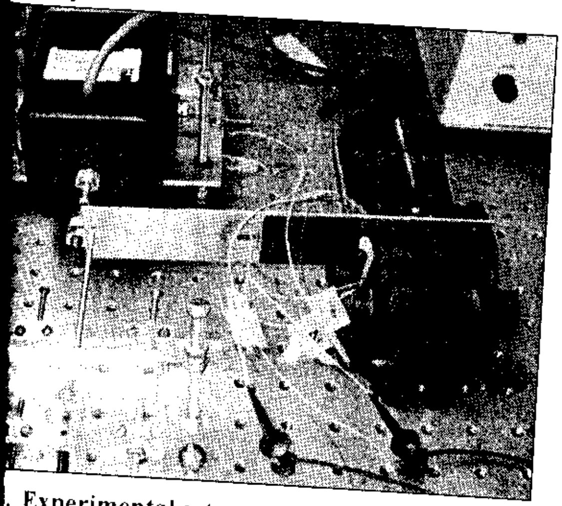
Piezoelectric materials are utilized in this application as actuators. Piezoelectric mate do not require radiation shielding and are fairly insensitive to temperature, unlike fiber optics electrostrictive materials such as lead-magnesium-niobate, (PMN) (Anderson et. al, 1990). Furthermore, the inherent rigidity of piezoelectric ceramic materials also leads to a more effi conversion of electrical to mechanical energy, ensuring good actuation capabilities.

Since the precision positioning requirements for active structures are in the order of microns, little to no vibration due to maneuvering of the spacecraft can be tolerated. Active control systems that rely on piezoelectric materials are effective in controlling the vibrations structural elements such as beams, plates and shells. Dimitriadis et al (1991) developed an lytical model for simply-supported, isotropic plates with bonded piezo patches. They have wn that it is possible to modify the shape of the actuator to either excite or suppress particular les leading to improved control behavior.

In terms of active panels for vibration suppression, various researchers have worked on embedded or surface-mounted sensors and actuators for composite and metallic plates, ns, and shells (Lee et al., 1998). Active panels have also been used for precision positioning. articular interest is the precision positioning of reflector dishes and antenna membranes kins et al., 1998). Active Composite Platforms (ACP) with precision positioning and ation suppression capabilities have not been developed.

METHODS

The basic design and material selection for the AAP and ACP prototypes were set before roject began. The piezo actuators were purchased from Active Control eXperts (ACX) for the AAP and ACP portion of the project and have widths of 38.1 mm, thickness of 0.51 and lengths of 50.8 mm. ACX piezo actuators were chosen because of ACX's previous ience with the vibration suppression of aluminum beams. The surface-mounting of the s was performed using the manufacturer's instructions with the adhesive they provided. AP and ACP dimensions were the same (152.4 mm-length and 38.1 mm-width) except for ickness due to the nature of the materials, which was 1.5875 mm and 2.032 mm, tively.



. Experimental setup used in the vibration ion tests of both the AAP and ACP. A shaker the end of the platform, and a fiber optic nses the platform tip displacement.

For the platform experiments, an external shaker was used to initiate a sinusoidal force at the end of the platforms, which was suppressed by the piezo actuators. The vibration suppression experimental results were compared to numerical results (ANSYS) to verify the numerical analysis.

The fiber optic sensor output was calibrated using strain gages mounted to the platform. The shaker applied an unknown input sinusoidal force to the respective platform. The outputs from the fiber optic sensor and the strain gages were recorded. With the strain known at that point on the platform, the tip displacement was then calculated. The maximum tip displacement of the respective platform from the ental results was used to determine the input sinusoidal force to be used in the numerical ons. The tip displacement for the experimental results was determined by calibrating the ic sensor used in the experiment. The input AC voltage to the piezos was incremented steps, and the resulting tip displacements were compared graphically. 80 V was not l to ensure the piezos would not exceed their performance capabilities.

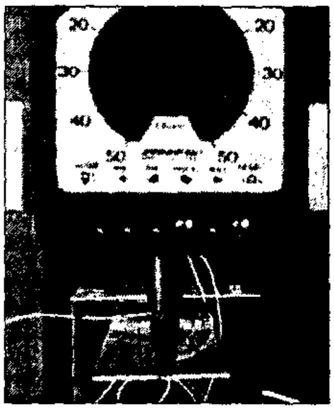


Figure 2. Experimental setup used in the precision positioning tests of both the AAP and ACP. A displacement sensor senses the tip displacement.

[illegible]ioning was tested using a dis[illegible] with micrometer accuracy, whi[illegible] at the end of the platforms to rea[illegible]nt. Again, the input DC voltage su[illegible] was incremented in 10-V steps fo[illegible]-V steps for the ACP. The co[illegible]as a higher stiffness and larger thic[illegible] did not displace enough to retrieve usab[illegible]aximum DC voltage used in the ACP[illegible] was set at 90 V because the displ[illegible]or could not measure the tip displ[illegible]oltages below 70 V and enough point[illegible]ed to show the linear relationship piezo[illegible] input voltage and displacement. An ampli[illegible]ed to amplify the voltage supplied to the pie[illegible] the experiments.

RESULTS

In the analysis portion, completed in the early stages of this project, a threshold voltage was discovered. This voltage is the maximum voltage allowable to suppress the vibration occurring from a specific input force. Applying a voltage higher than the threshold results in allowing the piezos to cause the vibration because the higher voltage begins to cause the piezos to excite the platform with a higher force than the input force. For instance, with an input sinusoidal force of 0.13 N at 35 Hz, the following results for the ACP model are shown for both the harmonic and transient analyses. The threshold voltage for the AAP and ACP were found to be 40 V and 20 V, respectively, for an input sinusoidal force of 0.13 N at 35 Hz.

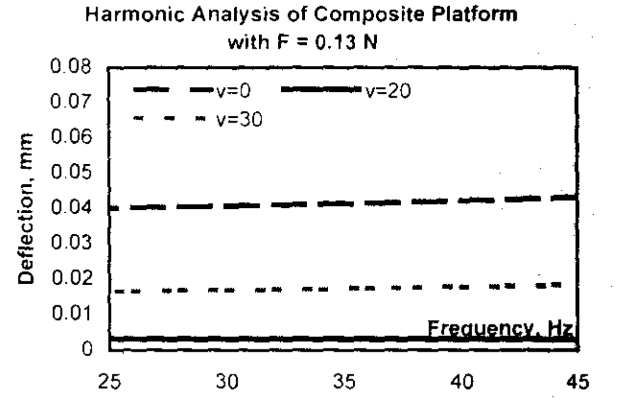


Figure 3. The threshold voltage is shown for the harmonic analysis performed for the ACP model. At 20 V, the input force is shown to be suppressed by the piezos. However, when 30 V is applied to the piezos, the tip displacement increases because the piezos are no longer suppressing the input vibration and are, in fact, causing vibration.

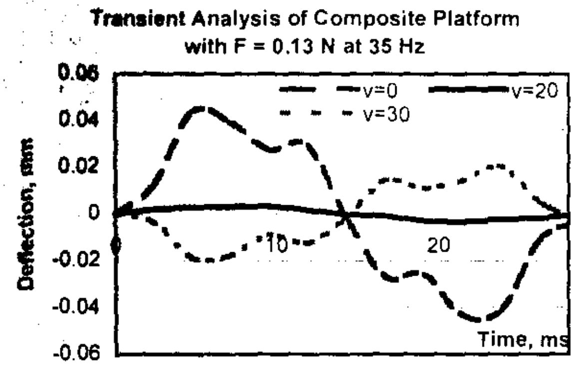


Figure 4. The threshold voltage is shown for the transient analysis performed for the ACP model. At 20 V, the input force is shown to be suppressed by the piezos. However, when 30 V is applied to the piezos, the tip displacement increases because the piezos are no longer suppressing the input vibration and are, in fact, causing vibration..

For incremented input AC voltages of 10 V, the experimental and numerical tip displacement results for the AAP and ACP are shown graphically in Figure 5 and Figure 6, respectively. The shaker was set to input a small sinusoidal force at 35 Hz that would displace the tip of the AAP and ACP approximately 1.22 mm and 0.156 mm, respectively. The input voltages used in the numerical analyses were applied with a gain factor of 4.53 for the AAP analysis and 0.76 for the ACP analysis. For instance, in the case of the AAP analysis, instead of 20 V at 35 Hz being applied to the piezos, 20 * 4.53 V, or 90.6 V at 35 Hz needed to be supplied to the piezos to achieve the correct physical tip displacement. The percent differences for the AAP experiment ranged from 0.3 % to 9.0 % for 70 V and peaked at 129% at 80V. The percent differences for the ACP experiment ranged from 0.3 % to 3.7 %.

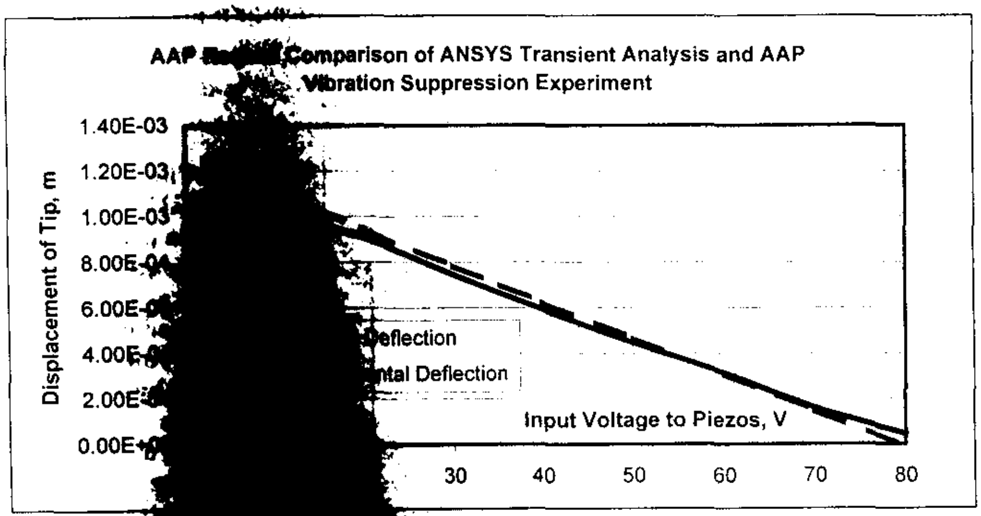


Figure 5. The comparison of the numerical transient analysis and experimental vibration suppression testing of the AAP are shown. For a predetermined input voltage (AC voltage incremented by 10 V at 35 Hz), the respective tip displacement is graphically shown.

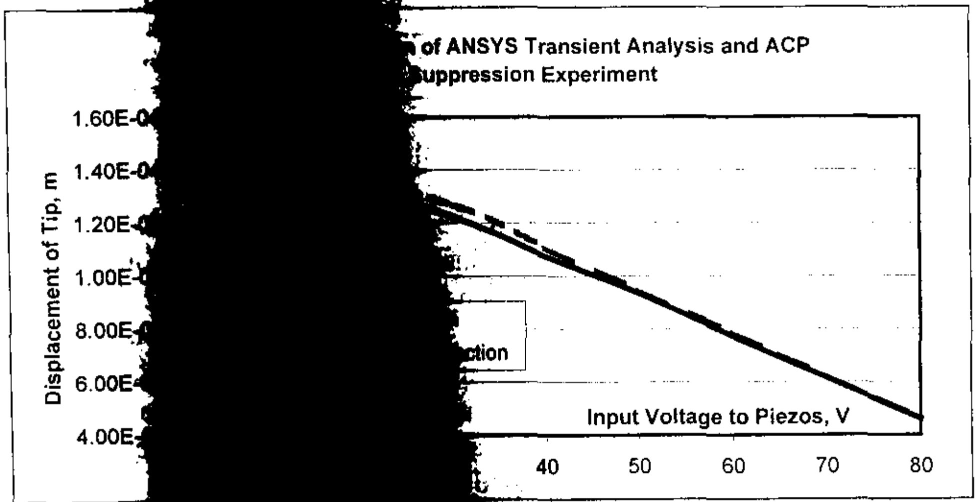


Figure 6. The comparison of the numerical transient analysis and experimental vibration suppression testing of the ACP are shown. For a predetermined input voltage (AC voltage incremented by 10 V at 35 Hz), the respective tip displacement is graphically shown.

T[illegible]he precision positioning of the AAP and ACP are shown below i[illegible]ctively. As expected, the displacement trend was linear. For the [illegible]as increased in steps of 10 V beginning with 20 V and ending [illegible]put DC voltage was increased in steps of 5 V beginning with 70[illegible]al of 12 trials were performed for each increment of input DC vol[illegible]

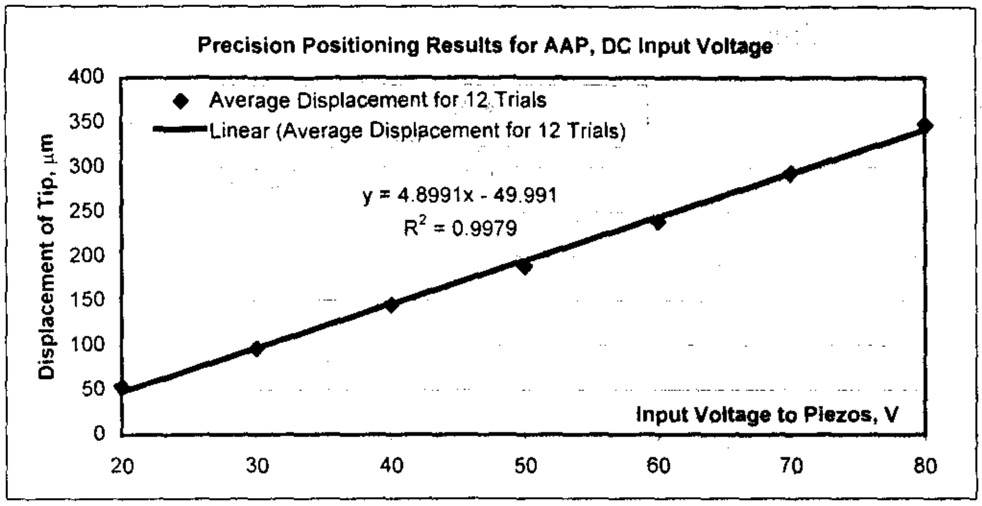


Figure 7. The experimental results for the precision positioning testing of the AAP are shown. For a predetermined input voltage (DC voltage incremented by 10 V), the respective tip displacement displayed on the micrometer-accuracy displacement sensor is graphically shown.

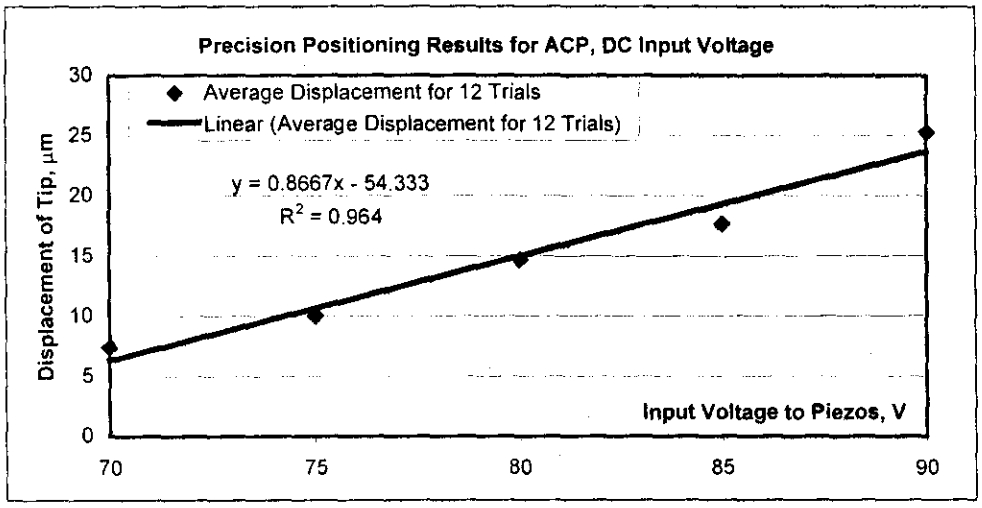


Figure 8. The experimental results for the precision positionin testing of the ACP are shown. For a predetermined input voltage (DC voltage incremented by 5 V), t respective tip displacement displaye on the micrometer-accuracy displacement sensor is graphically shown.

DISCUSSION

The vibration suppression results for the AAP and ACP experiments were satisfactory. The 35 Hz frequency for the sinusoidal input was chosen because it ensured the excitation sta away from the natural frequencies of the AAP and ACP, which were 85.608 Hz and 142.48 H respectively. The large percent difference seen at 80 V for the AAP results can be attributed the difficulty in accurately reading the output signal from the fiber optic sensor displayed by dynamic signal analyzer in the 500 μV/div range. It was also noted that when shearing an aluminum sheet to a small width of 38.1 mm, the resultant beam could not be made perfectly The composite material, on the other hand, is much stiffer and when cut, even to a small wid 38.1 mm, does not warp. Thus, it is possible that the AAP was not reacting to the external vibration as the numerical analysis predicted and explains the larger percent differences seen the AAP vibration suppression comparison when compared to the ACP vibration suppressio comparison.

The precision positioning results for the AAP and ACP experiments were also satisfactory. During the experiments, it was realized that the displacement sensor was not a read any tip displacement for low input DC voltages. Thus, the AAP experiment was run i increments of 10 V from 20 V to 80 V. The ACP experiment was run in increments of 5 V

70 V to 90 V. Due to the increased stiffness and thickness of the ACP because of the use of composite material, a higher voltage range was required. Thus, to establish a trend with the experimental data, the input DC voltage was incremented by 5 V. The correlation factors resulting from the AAP and ACP experiments were 0.998 and 0.964, respectively. These results were satisfactory and showed the linear trend expected with input voltage and displacement of the piezos.

CONCLUSION

An ACP prototype was designed, manufactured, tested and analyzed with satisfactory esults. The ACP showed that it was able to suppress an external sinusoidal vibration when upplied an input AC voltage at the same frequency but out of phase, which was verified using umerical analysis, as well as precisely position its tip when supplied an input DC voltage.

Future improvements for this project would be to obtain a more sensitive sensor that is apable of nanometer accuracy so that the ACP prototype can be tested for smaller isplacements. Also, using more strain gages in different locations would allow for a more ccurate calibration of the fiber optic sensor. Finally, the use of a more accurate reading device an the dynamic signal analyzer's CRT screen, such as LabVIEW, would provide clearer data trieval.

ACKNOWLEDGEMENTS

The author would like to thank NASA and the Hawai'i Space Grant College for providing with the opportunity to do research and design in my field. Thanks goes out to Mark Uyema, eid Pourjalali, and Mr. Northrup Castle for all their assistance during the analysis and nufacturing portion of this project. The author would also like to thank Dr. Mehrdad Nejhad being her mentor for the past year.

REFERENCES

derson, E. H., Moore, D. M., and Fanson, J. L. (1990) Development of an active truss element for control of precision structures. Optical Engineering, Vol. 29, No. 11, pp. 1333 - 1341.

itriadis, E.K., Fuller, C.R., and Rogers, C.A. (1991) Piezoelectric Actuators for Distributed Vibration Excitation of Thin Plates. *Journal of Vibration and Acoustics*, Vol. 113, pp. 100-107.

ins, C. H., Kalanovic, V. D., Faisal, S. M., Padmanabhan, K., and Tampi, M. (1998) Adaptive Shape Control of Precision Membrane Antennae and Reflectors. Proceedings of ASME International Mechanical Engineering Congress and Exposition, Adaptive Structures and Material Systems, Sirkis, J., and Washington, G., Eds., New York, AD-Vol. 57, MD-Vol. 83, pp. 177-188.

Y.Y., Mei, C., and Huang, J-K. (1998) Control of Random Vibrations of Composite Plates with Piezoelectric Actuators. Proceedings of ASME International Mechanical Engineering Congress and Exposition, Adaptive Structures and Material Systems, Sirkis, J., and Washington, G., Eds., New York, AD-Vol. 57, MD-Vol. 83, pp. 109-127.