DESIGN, MANUFACTURE, AND TESTING OF A COARSE/FINE ACTIVE COMPOSITE STRUT PROTOTYPE WITH VIBRATION SUPPRESSION AND PRECISION POSITIONING

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ABSTRACT

Intelligent structures, capable of sensing and responding to their environment, present an ideal means of satisfying the rigorous performance requirements of space missions. The objective of this research was to design an active strut prototype with simultaneous vibration suppression and precision positioning capabilities to be utilized in an experiment. This work takes advantage of the basic understanding of science and technology developed by former space grant students Kevin Fong, Lucy Wong, Mike Lambert, Grace Leung, Gay Leong, Carl Lee, Dan Sakata, and Jessica Hiraoka. The active strut developed by former fellows made use of inchworm mechanisms to achieve positioning in the range of millimeter with micron accuracy employing piezoelectric stacks. Although the inchworm mechanism achieved the general goals, it had drawbacks in terms of clamping effects and systematic inaccuracies associated with it. Therefore, in this strut prototype, the inchworm mechanism was replaced with a combination of motor and piezoelectric for coarse and fine positioning, respectively. The manufactured prototype has been tested for vibration suppression, precision positioning, and simultaneous vibration suppression and precision positioning.

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), are utilized in this application and can function 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 which should simplify data acquisition and control of the structural response (Newnham and Ruschau, 1993).

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 [illegible] tures are on the order of microns, little to no vibration due to maneuvering of [illegible] can be tolerated. As a result, it is desirable for the active struts to possess active vi [illegible] ssion capabilities to a) avoid any inaccuracy and malfunctioning of the device du [illegible] noises (i.e., sources of vibration), and b) contribute to the overall vibration suppre [illegible] tire structure. Active control systems that rely on piezoelectric materials are effe [illegible] ling the vibrations of structural elements such as beams, rods and struts. Many of t [illegible] signs for large flexible structures are truss-type structures. One obvious approach [illegible] an adaptive structure is to replace certain passive members of the truss structure w [illegible] bers or extensible links and appropriate joints. The active members or strut [illegible] load carrying members as well as actuator/sensor pairs.

Active st [illegible] y been used for vibration suppression to maintain precision positioning rather [illegible] recision positioning function. Dr. Nejhad and his former space grant students hav [illegible] hworm system in an active strut for precision positioning with a relatively low lo [illegible] bility. Active Composite Struts (ACS) with simultaneous precision position [illegible] n suppression capabilities have not been developed.

The main [illegible] this research is to design, manufacture, and test an active composite strut (A [illegible] ve vibration suppression and precision positioning capabilities for use in space [illegible] individual tasks include: developing an understanding of the fundamentals of [illegible] terials behavior including the electro-mechanical constitutive equations and ma [illegible] ties modeling, background study on composite materials, familiarization with [illegible] strut system developed by the former space grant fellows mentioned earlier i [illegible] calibration of piezoelectric sensors and actuators, design and manufacture of a co [illegible] ing that can embody multiple components such as piezoelectric as well as precision [illegible] ne and coarse positioning and vibration suppression as well as performing precisio [illegible] and vibration suppression experiments and data collection. In addition, the relatio [illegible] piezoelectric sensors and actuators voltage input/output and the displacements [illegible] ation damping of the ACS as the intelligent structure will be established.

METHODS

The strut [illegible] shown in Figure. [illegible] actuator for coa [illegible] and a piezoelect [illegible] actuator for [illegible] positioning an [illegible] suppression. Th [illegible] coarse positioni [illegible] 227.50 High Reso [illegible] Loop DC-Mi [illegible] manufactured [illegible] Instrumente. The [illegible] an ultra-high re [illegible] actuator providin [illegible] up to 50 mm [illegible] micrometer resol [illegible]

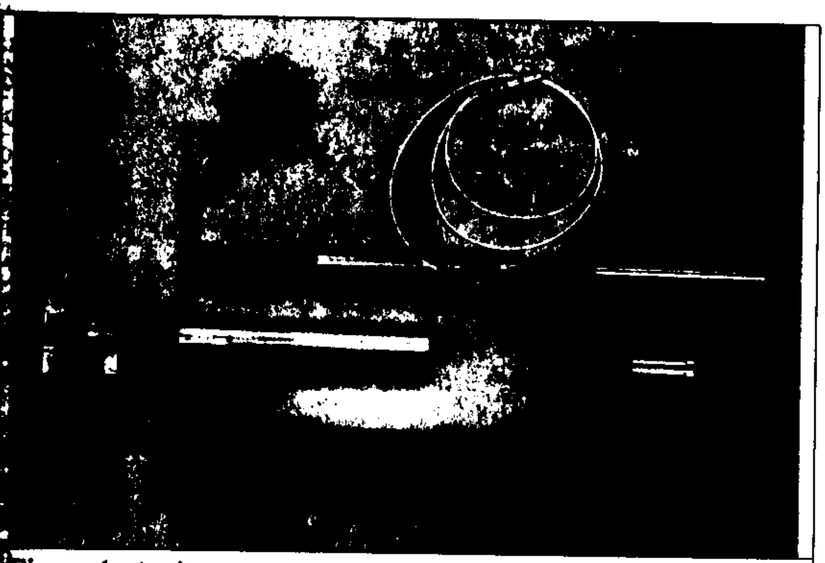

Figure 1: Active strut prototype components

push/pull force of 100 N, driven by a closed-loop DC motor/gearhead combination with motor shaft mounted high-resolution encoder. To control the actuator, the C-842 DC Motor Controller PC Board, also manufactured by Physik Instrumente, was used. This board and the included control program was installed in a computer to control the M-227.50 actuator. The piezoelectric actuator for precision positioning and active vibration suppression is the PA 25/12-stack type actuator manufactured by Piezosystems Jena. This actuator offers displacement up to 25 μm at 150 volts, sub-nanometer resolution, and a pushing capacity of 1000 N.

The components of the active strut prototype are housed in a composite tubular housing. The composite tube was manufactured using a roll wrapping technique and measures 13" long with an inner diameter of 1" and a thickness of 0.08". T300/934 preimpregnated graphite/epoxy plain weave cloth was used. An aluminum end cap was also manufactured to enclose the housing. Further, the end cap contains a Thomson Industries, Inc. Super 8 linear bearing to ensure precise motion of the strut's extension arm.

As the strut is to be utilized in a tilting platform, research on precision joints to offer two-degrees-of-freedom movement was also been conducted. These joints are very important in the design of the platform to offer the correct motion and maintain the precision of the strut. A joint prototype was also developed utilizing bearings and precise tolerances to ensure precise motion and precision.

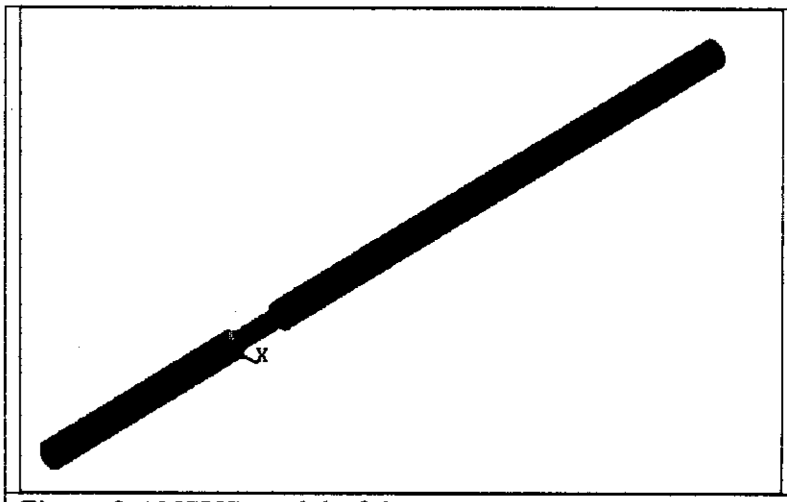

Figure 2:ANSYS model of the strut prototype.

FINITE ELEMENT ANALYSIS

Finite element analysis using ANSYS was conducted for vibration suppression of the Active Composite Strut. Modal, harmonic, and transient analyses were conducted on a model of the complete strut. The model consisted of the actuator, piezoelectric stack, and the strut's shaft. The model used for the analyses is shown in Figure 2. The modal analysis yielded the first 4 modes of axial vibration for the structure at 4026 Hz, 8753 Hz, 15443 Hz, and 18507 Hz. In the harmonic analysis, a pressure of 190,000 Pa, equivalent to a 5.25-pound force, was applied to the end of the shaft with various voltages applied to the piezo. The

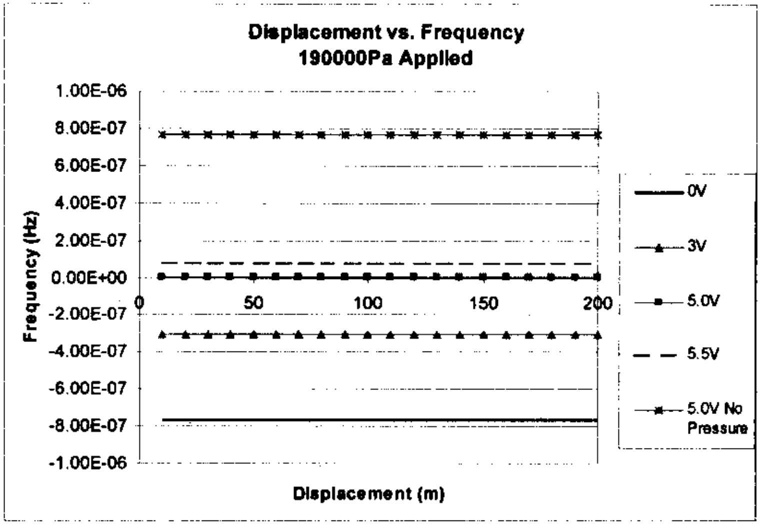

Figure 3:Harmonic analysis 0-200Hz - Displacement of the shaft tip at various applied voltages.

resulting disp[illegible] the shaft tip for fre[illegible]ween 0 and 200Hz a[illegible]igure 3. This graph[illegible] the maximum supp[illegible]2% is obtained wit[illegible] to the piezo. Above[illegible] the piezo itself [illegible] the vibration. Tran[illegible] was also conducted [illegible]del. Similar to the h[illegible]ysis, simulations [illegible]cted applying 190,00[illegible]haft end at 100Hz. [illegible]ges were applied [illegible] to cancel out the d[illegible] The results are show[illegible]re 4. The maximum su[illegible]was obtained by applying 5V to the piezo, matching the harmonic analysis conduct[illegible] Again matching the harmonic analysis, voltages above 5V began to excite the shaft.

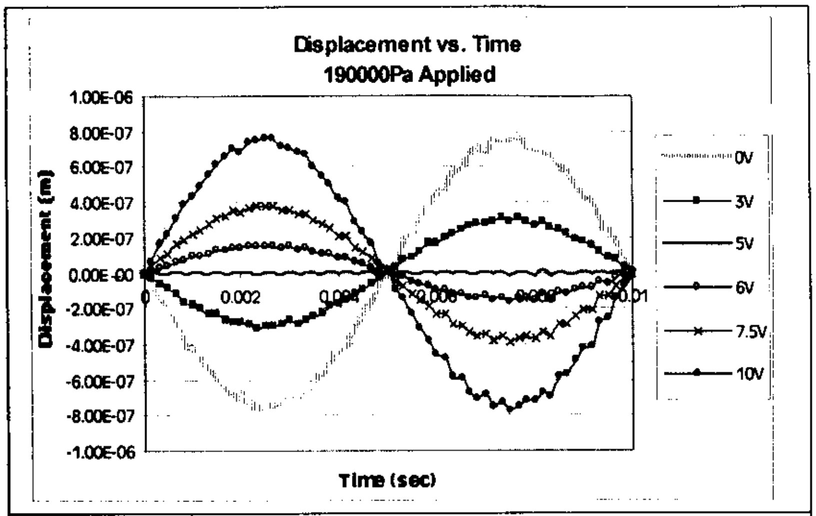

Figure 4: Transient analysis at 100Hz - Displacement for 190,000Pa applied to shaft tip.

RESULTS AND DISCUSSION

Precision positioning tests were performed on the assembled strut. The test setup is shown in Figure 5. The assembled strut was mounted vertically on a test platform. The displacement sensor used was precise to one micron. Using the control program for the actuator, the strut was extended up and down one micron at a time for ten steps. A second test was conducted with 5 steps of 10 microns up and down. The strut performed both tests successfully. A third positioning test was performed to calibrate the piezo. DC offset voltage was applied to the piezo to extend it. Measurements were verified by micrometer and matched very well with the manufacturer's calibration sheet. A maximum displacement of 30 microns was obtained with 144.39 Volts applied to the piezo.

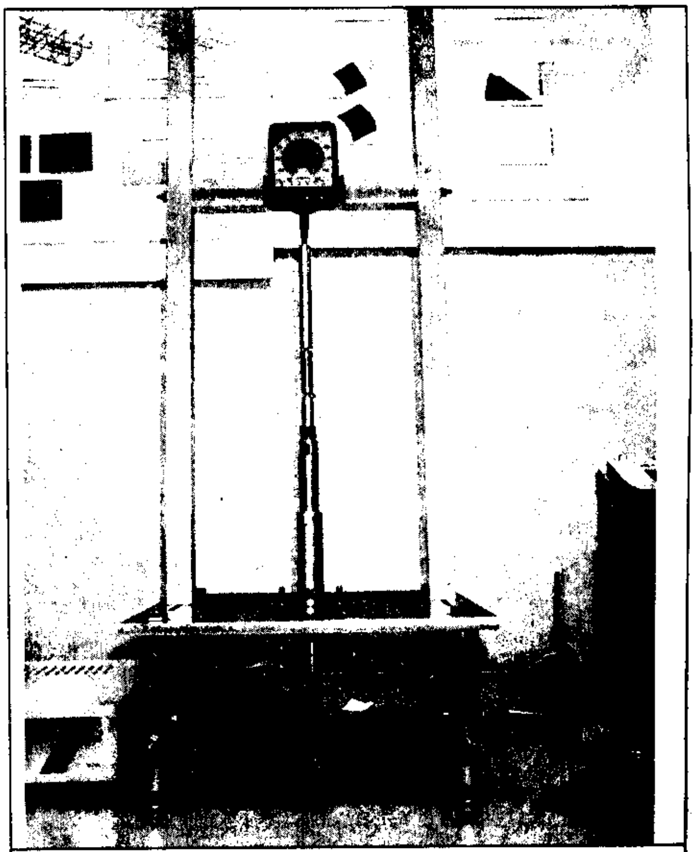

Figure 5: Precision positioning test setup.

Vibration suppression tests were conducted on the complete strut assembly using an ET-132 Electrodynamic Transducer as an axial vibration input.

The back end of the strut was clamped in a vice and bolted to a vibration table. A D100 fiber-optic sensor made by Philtec was used to measure the displacement of the strut's shaft tip. The test setup is shown in Figure 6. Tests were performed while applying 1, 2, 5, 7.5, and 10V signals to the piezo at 100Hz. The amplitude of the shaker's displacement was adjusted to match the piezo's displacement. Measurements were taken for the shaker's displacement and the displacement with the piezo's suppression using the fiber-optic sensor. The output of the shaker was also measured using the piezo as a sensor. The results are summarized in Table 1 below.

Simultaneous precision positioning and vibration suppression was also tested. While the piezo suppressed the shaker signal, the actuator was extended 5 microns in 1-micron increments using the control program, and then retracted. The piezo was also used for precision positioning. While it suppressed the vibration, a DC offset voltage was applied to extend the piezo. In both cases, the vibration suppression remained effective with no loss of vibration suppression.

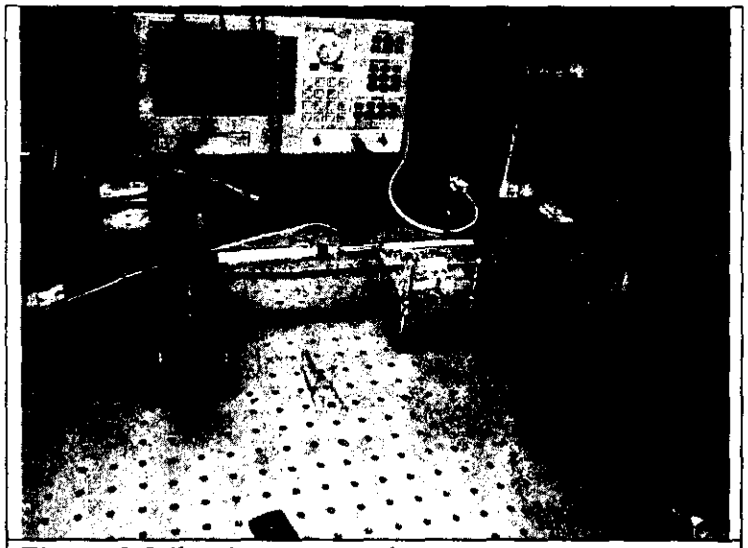

Figure 6: Vibration suppression test setup.

Piezo Input (V)	Unsuppressed Vibration (mV)	Piezo Sensor Reading (mV)	Suppressed Vibration (mV)	Suppression
1	5	67	0.5	90.00%
2	8.5	100	1.75	79.41%
5	27	320	2	92.59%
7.5	45	480	4	91.11%
10	60	650	5	91.67%

Table 1: Summary of vibration suppression tests.

CONCLUSIONS

The active strut prototype performed very well in all of the tests performed. In the positioning test, the actuator was able to demonstrate consistent accuracy in the micron range, as did the piezo. Because the sensitivity of the displacement sensor was limited to the micron range, the actuator and the piezo's full precision could not be tested, however. In the vibration suppression tests, the piezo was able to suppress over 90% of the vibration for most cases. This data could not be related to the ANSYS analysis because force measurements were not available in the vibration tests. However, further analysis demonstrated a linear relationship between the maximum vibration displacement and piezo voltage. In both the ANSYS simulations and the vibration suppression tests, a linear relationship existed between the maximum displacement amplitude and the voltage required to suppress the vibration displacement.

Further tests should be performed on the strut using a force transducer and more sensitive displacement sensors so that the full precision of the strut can be realized. Additional struts should also be manufactured and tested for use on a platform. A control system should also be designed for the complete platform with active struts.

Overall, the active strut prototype succeeded in meeting the design objectives. The strut prototype was built and successfully performed precision position, vibration suppression, and simultaneous precision positioning and vibration suppression. The full precision of the strut prototype has not been tested, but the simultaneous positioning and vibration suppression it offers has not been previously available. The use of active struts in tilting platforms will offer great benefits in communications and space applications as well as other precise applications.

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