TROUBLE-SHOOTING, ASSEMBLY, AND TESTING OF A PIEZOELECTRIC ACTIVE STRUT FOR SPACE STRUCTURES

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ABSTRACT

Active struts can serve dual functions as structural members and actuators. The piezoelectric active struts of this project possess precision-positioning capability; e.g., the change in length of the strut is controllable on the micron level. An inchworm technology magnifies the displacement of the actuator, a piezoelectric ceramic stack made of lead zirconate titanate (PZT). The precision positioning capability is the focus of this research. Over the past year, many modifications were made to a single miniature piezoelectric active strut, resulting in significant improvements in strut operation. Before modification, the strut worked in non-loaded non-inchworm mode, but not in any other mode. With the modifications, the strut now also works in loaded non-inchworm mode and non-loaded inchworm mode. Loading the strut up to 5 pounds does not significantly reduce the non-inchworm mode performance. The non-loaded inchworm mode test results are within ±15% of the expected performance. Reducing clamping system alignment problems and increasing clamping force may help to improve the non-loaded inchworm mode and make the loaded inchworm mode operational. The declining piezo performance must be addressed before the strut can be used extensively as an actuator.

INTRODUCTION

Active struts can serve dual functions as structural members and actuators. In this project, miniature piezoelectric active struts are being developed for their precision positioning capability. Piezoelectric ceramic stacks stack made of lead zirconate titanate (PZT) are used as the actuators, providing axial displacement control of micron magnitude. The active strut of this research uses an inchworm technology to magnify the micron displacements of the piezoelectric stacks. The desired overall displacement of the active strut is 500 to 1000 microns, as the maximum achievable displacement of currently available active struts of less than 50 microns greatly limits their usefulness in current space structures. A potential application is to employ three active struts in a precision positioning platform. The three struts would extend or contract to tilt the platform to achieve 1 degree of motion.

The primary objectives of this research were to perform final trouble-shooting and testing of an active strut in both its non-inchworm and inchworm modes (with and without loading). The objective of the testing was to produce voltage-displacement and voltage-load-displacement curves for the strut. This report concludes one year of work (Spring, Summer, and Fall 98 semesters) and summarizes the modifications made and the test results.

METHODS

At the start of Spring 98, the strut operated solely in its non-loaded non-inchworm mode. Many modifications were made after investigation of the slipping problem reported by former Space Grant recipient Carl Lee. After modification, the strut now additionally works in loaded non-inchworm mode and non-loaded inchworm mode. The modifications are discussed in the next two paragraphs.

It was observed that rubber brake pads, which clamp the piezo-block assembly to support load, elastically shear under load and cause displacement loss. Shearing problems persisted after modifying the rubber brake pads, so an alternative material was needed. During Summer 98, four different brake pads were installed on the strut and compared. Carbon epoxy composite was the brake pad material with the best combination of load supporting capacity, wear resistance, and shear resistance. Table 1 shows a summary of the brake pad material comparison.

TABLE 1 SUMMARY OF BRAKE PAD MATERIAL COMPARISON

Material	Load Capacity [lbs.]*	Wear Resistance**	Shear Resistance***
Carbon epoxy composite	5	Good	Good
3003 Aluminum sheet	2	Good	Good
Triacetate plastic sheet	2	Good	Good
SBR rubber	Not available	Good	Poor
600 grit sandpaper on metal	7	Poor	Good

* Load Capacity: maximum static weight supported by strut.

** Wear resistance: considered good if material did not need replacement during testing, poor otherwise.

*** Shear resistance: considered good if strut supported static load without displacement loss greater than maximum piezo extension, poor otherwise.

Switching to incompressible brake pads required changing the twin double-lobed cams, which control the clamping system timing, and the follower arms. With the original cams, four 60-degree transitions occur every revolution when neither pair of clamps fully activates, causing displacement loss. With the new cams, at least one pair of clamps is fully activated at any time. Figures 1 and 2 show the displacement curves generated by the new and original cam pairs, respectively. Each curve corresponds to the clamping action of one pair of brakes. The maximum for a curve corresponds to a fully activated brake; the minimum corresponds to a fully unclamped brake. Figure 1 shows that over an entire revolution, at least one curve is always at its maximum, so at least one brake is fully active at any time. The new cams were manufactured with a computer numerically controlled (CNC) machine. The follower arms were machined thicker to resist bending and to apply more clamping force.

Fig. 1 Timing diagram for new cam pair, showing that at least one clamp is always fully activated.

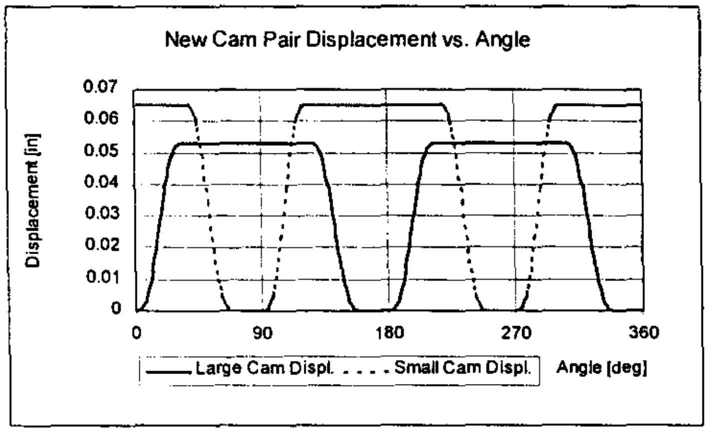
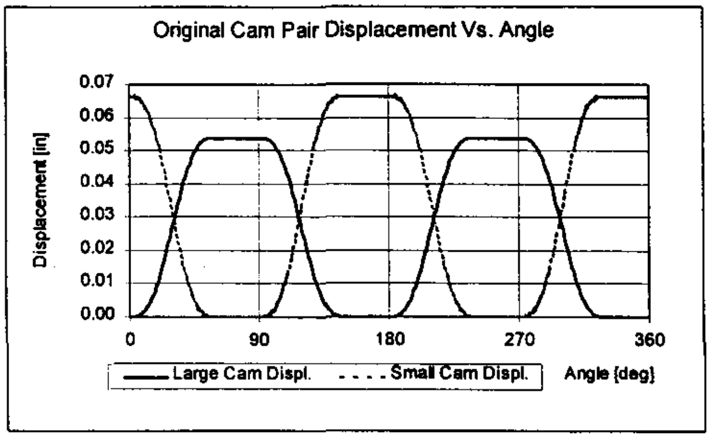


Fig. 2 Timing diagram for original cam pair, showing four transition periods * when neither clamp is fully activated.



Other modifications included tripling the brake pad surface area to increase the load carrying capacity, and using shims to reduce unwanted lateral motion of the follower arms.

During testing, several pieces of equipment were used. The piezo was powered with a HP 6236B power supply, amplified by a Trek Model 601B-4 operational amplifier to reach the necessary maximum voltage of 200 V DC. A HP 3466A digital multimeter was used to read the piezo voltage. The strut was held in place with the test stand built by Lee, and displacement measurements were taken with a Maxµm DEI 15111E1 digital electronic indicator.

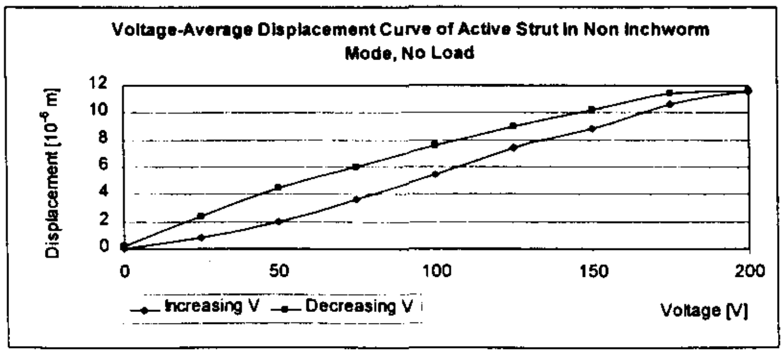
The modified strut was tested in non-inchworm mode (without and with loading) and in inchworm mode (without loading) for displacement response to input voltage. In non-inchworm mode, the strut was tested with 0, 1, 3, and 5 pound loads. At each load, five trials were performed; in each trial, voltage was incremented by 25 V from 0 V to 200 V, and back to 0 V. Displacement was measured after each voltage increment. In inchworm mode, the strut was tested with no load for nine trials. A trial consisted of using the inchworm to extend the strut for ten piezo excitations, and then using the inchworm to contract the strut for ten piezo excitations. For each piezo excitation, the voltage was increased from 0 V to 200 V for maximum displacement. Displacement was recorded after each voltage change, and after each time the follower arms clamped the piezo – block assembly. Statistics are reported for total net displacement at the end of the extend process and contract process, and for non-piezo net displacement. The non-piezo net displacement is the total net displacement minus the piezo displacement; it indicates how much of the total net displacement is due to error.

RESULTS

The results of the non-inchworm tests are shown below in Figures 3-6 for 0, 1, 3, and 5 pounds. Statistics are shown with the figure labels.

Fig. 3
Average maximum displacement = 11.6 microns

Standard deviation = 0.548 microns



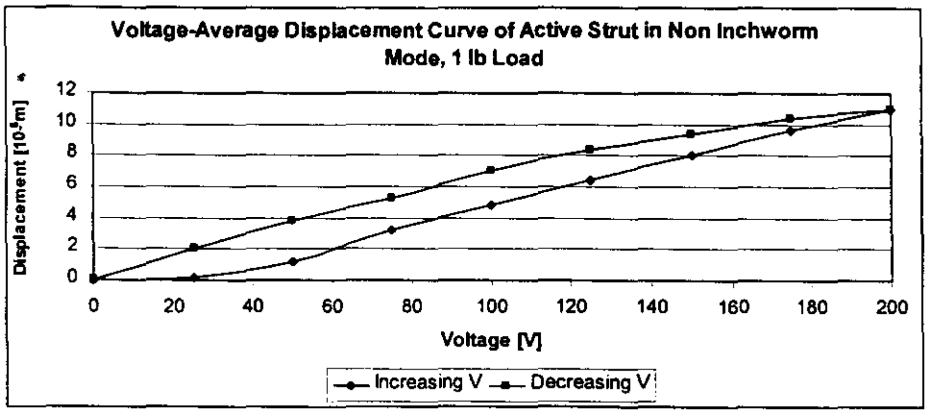


Fig. 4
Average maximum displacement = 11.0 microns

Standard deviation = 0 microns

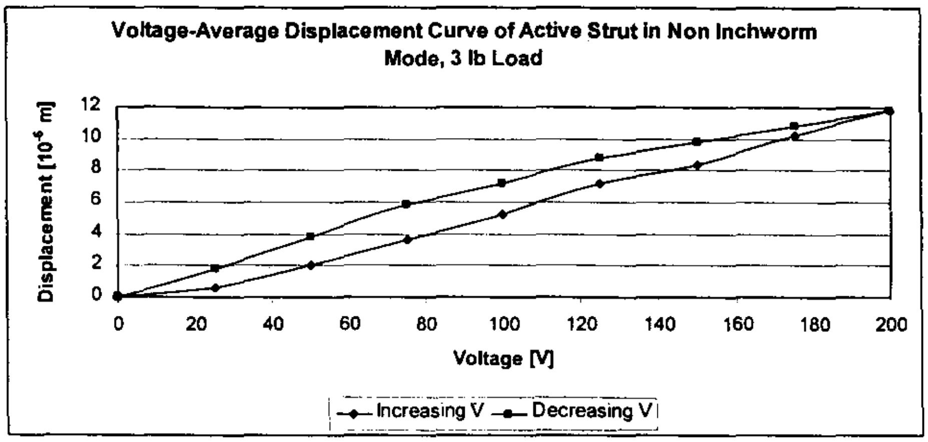


Fig. 5
Average maximum displacement = 11.8 microns

Standard deviation = 0.447 microns

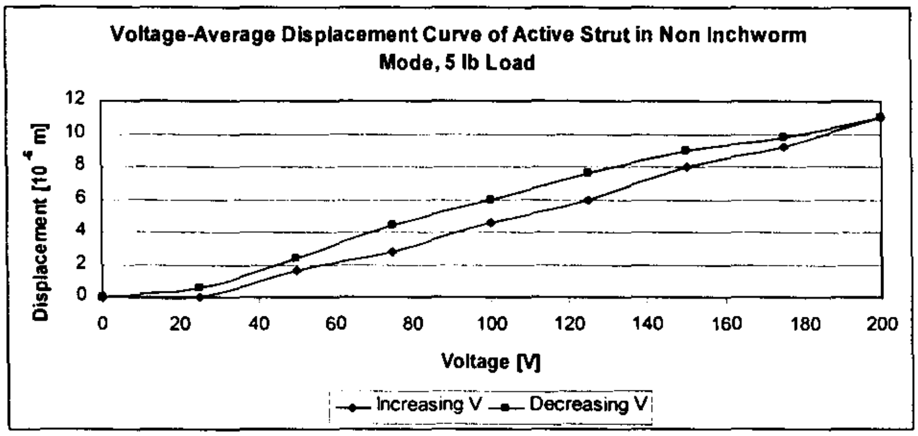


Fig. 6
Average maximum displacement = 11.0 microns

Standard deviation = 0.707 microns

Table 2 summarizes the results of the non-loaded inchworm tests. Positive displacements are in the positive vertical direction, and negative displacements are in the negative vertical direction.

TABLE 2 RESULTS OF NON-LOADED INCHWORM TESTS

	Total net displacement [μm] per 10 cycles			Non-piezo net displacement [μm] per 10 cycles		
Inchworm operation	Range	Average	Standard deviation	Range	Average	Standard deviation
Extend	61 to 104	86.3	15.7	-39 to 5	-13.7	16.3
Contract	-96 to –134	-110.2	13.0	-31 to 11	-9.2	14.1

DISCUSSION

Figures 3-6 show very similar results from the loaded non-inchworm tests. In addition, the average displacement at the maximum voltage is about the same for the various loads, so the performance of the non-inchworm mode does not significantly change for increasing load up to 5 lbs. The non-inchworm mode tests confirm that the piezo can support load and actuate, and that the strut supports load without significant displacement loss.

Note the hysteresis error between the increasing and decreasing voltage parts of Figures 3-6. The error worsens with piezo use. After one year of research, the maximum piezo extension decreased from 14 to 8 microns. The decreased performance may result from non-axial loads creating stresses in the piezo, or from fatigue. It is likely that there are non-axial loads on the piezo, as the follower arm clamping action can cause misalignment between the piezo-block assembly and the aligning end-cap bearing. Addressing the declining piezo performance is necessary before the strut can be used extensively as an actuator.

The results of the non-loaded inchworm testing are promising. At test time, the maximum piezo extension was about ten microns, so for ten full excitations the strut's average net displacement should be 100 microns extension or –100 microns contraction. The actual averages of 86.3 microns extension and –110.2 microns contraction are within ±15% of the expected performance. The discrepancy comes from the non-piezo displacement; subtract the average non-piezo displacement from the average net displacement, and the result is very close to the expected 100 microns. The non-piezo displacement may be caused by the misalignment problem mentioned earlier. Another possible source is that the brake pads do not always clamp flush to the block surface, a result of switching to the non-rubber pads. The non-piezo displacement problem should be solved to take full advantage of the piezo extension, and to improve the strut performance.

The strut requires further trouble-shooting to operate the loaded inchworm. The strut loses most of the piezo displacement during the clamping / unclamping action. The fact that this effect worsens due to increased loading (compared to the non-loaded inchworm) indicates that the clamping force needs to be increased in addition to the misalignment problem.

CONCLUSION

Over the past year, many modifications were made to a single piezoelectric active strut, resulting in significant improvements in strut operation. Before modification, the strut worked in non-loaded non-inchworm mode, but not in any other mode. With the modifications, the strut now also works in loaded non-inchworm mode and non-loaded inchworm mode. Loading the strut up to 5 pounds does not significantly reduce the non-inchworm mode performance. The non-loaded inchworm mode test results are within ±15% of the expected performance. Reducing clamping system alignment problems and increasing clamping force may help to improve the non-loaded inchworm mode and make the loaded inchworm mode operational. The declining piezo performance must be addressed before the strut can be used extensively as an actuator.

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