N93-18827

STATIC AND DYNAMIC CHARACTERISTICS OF A PIEZOCERAMIC STRUT

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ABSTRACT

The experimental study of a piezoceramic active truss strut is presented. This active strut is unique in that the piezoceramic configurations allow the stroke length of the strut not to be dependent on the piezoceramic material's expansion range but on the deflection range of the piezoceramic bender segment. A finite element model of a piezoceramic strut segment was constructed. Piezoceramic actuation was simulated using thermally induced strains. This model yielded information on the stiffness and force range of a bender element. The static and dynamic properties of the strut were identified experimentally. Feedback control was used to vary the stiffness of the strut. The experimentally verified model was used to explore implementation possibilities of the strut.

INTRODUCTION

This paper presents the static and dynamic characteristics of a new active piezoceramic strut. The actuation mechanism is based on strain induced bending. A prototype strut has been constructed, modelled and tested. The results of this experimental investigation will lead to the development of parameters for a strut to improve vibration suppression in the NASA Langley Research Center evolutionary model.

The primary motivation for the investigation of this actuator is that the strut's stroke length is independent of the expansion range of the piezoceramic and the strut performs the same whether a tensile or compressive load is applied to it.

STRUT DESCRIPTION

The device consists of a series of bender elements connected by a rigid shaft. These bender elements consist of a thin metal plate (Figure 1) with piezoceramics laminated to opposite sides. The poled direction of the piezoceramics is aligned so that a voltage applied across the bender element contracts one side and expands on the other. Straining the piezoceramics results in a bending motion of the element. A shaft joins the bender elements in a parallel configuration. This results in an additive effect of the individual bender elements. The total applicable force, stiffness and structural load bearing ability of the strut increases as the number of bender elements increases.

A prototype bender element strut was constructed. The limitation of material availability was the primary factor in the selection of the bender element size. The prototype used two bender elements for actuation. The piezoceramic disks where made of Piezo Electric Products Inc. lead zirconate titanate G-1195 material. A two part epoxy was used to laminate the .01" thick piezoceramic material to a .01 inch thick 6061-T6 aluminum disk. Figure 2 details the dimensions of the strut.

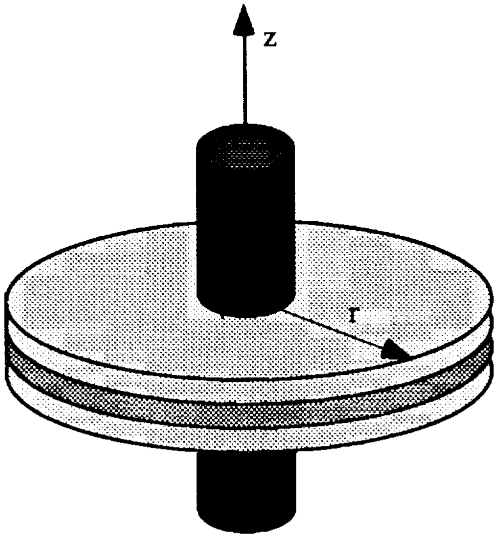

Figure 1. Single bender element

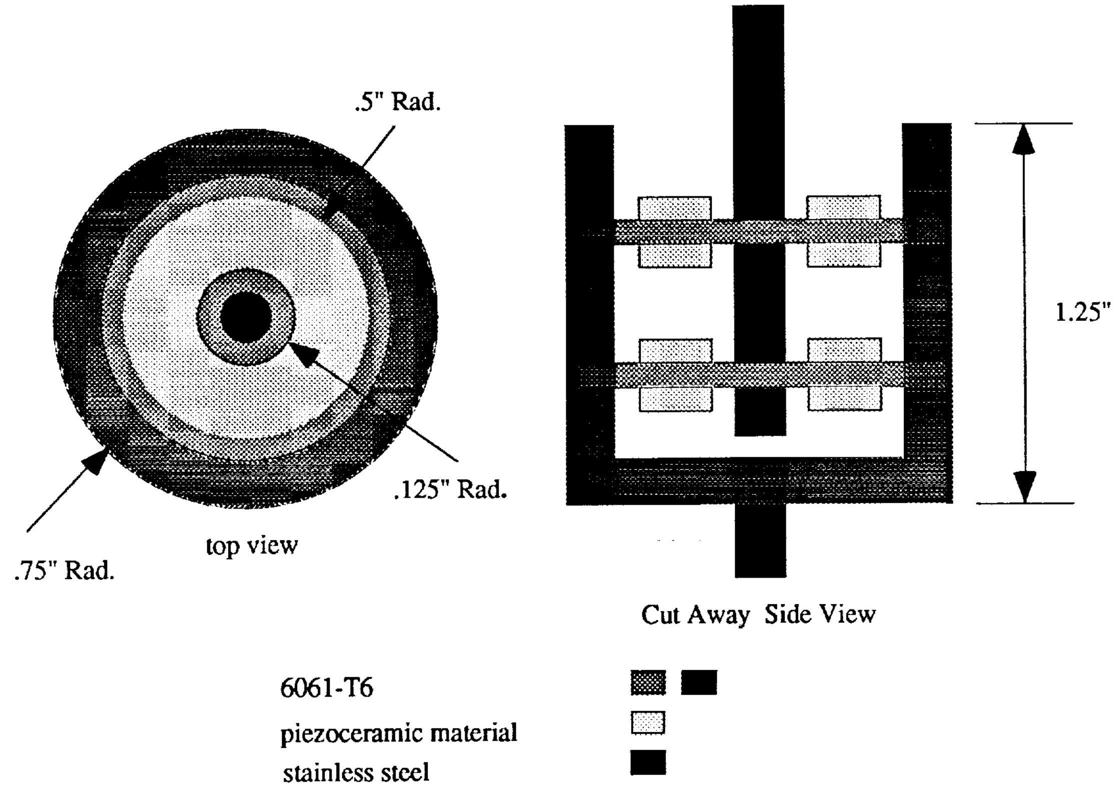

Figure 2. Prototype strut

FINITE ELEMENT ANALYSIS

A finite element model of the prototype strut was constructed. A cross section of one bender element was modelled. Axisymmetric trapezoidal rings were used to model the bender element. The motion induced on the bender elements from the expansion and contraction of the piezoceramic disks was simulated by applying a temperature load to the nodes of the bender element modelled. The results of this model were extrapolated to model the prototype strut (Table I). The finite element modelling process is essential to the refinement of the strut 's geometry. An increase in the force to stiffness ratio through a more efficient geometry is necessary and possible using the finite element modelling technique.

Table I. Finite element results

	Stiffness (lbf/in)	Max force range (lbf)
Finite element prototype model	10052	.604

EXPERIMENTAL RESULTS

The prototype bender element strut was evaluated experimentally. This evaluation investigated the static and dynamic properties of the strut. Two experiments were conducted. The first experiment involved placing the prototype strut between two rigid plates and a force transducer (Figure 3). A voltage signal was applied across the bender elements to strain the piezoceramic material. Time histories and transfer functions between the input voltage and force transducer output were recorded. The second experiment consisted of clamping the base of the strut to a rigid mass and forcing the active end of the strut with a regulated and measured force. A voltage proportional to the forcing signal was input into the strut. Displacement measurements during the experiment were acquired using optical displacement sensors.

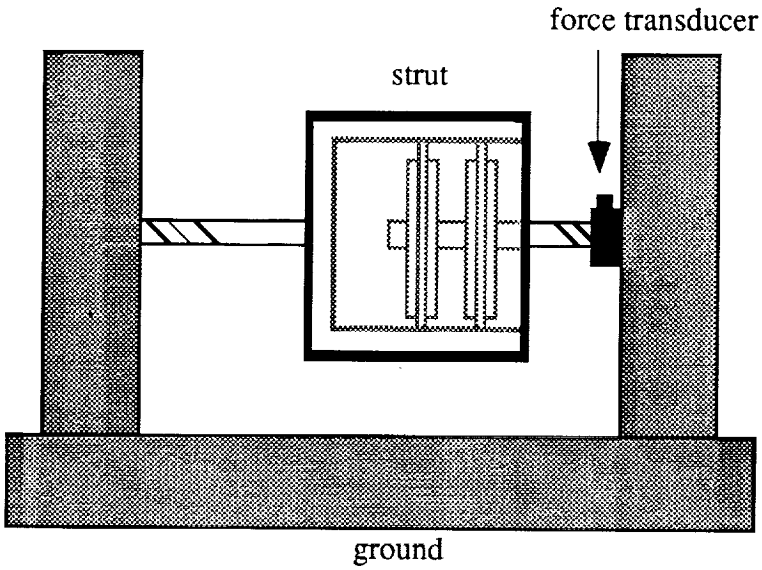

Figure 3. Experimental configuration

The result of forcing the strut at 5 Hertz between 2 rigid masses is shown in Figure 4. Figure 4 displays the force applied to the transducer verses the voltage applied to the bender elements of the prototype strut. Hysteresis appears due to the energy that is stored as elastic strain energy. The hysteresis is primarily due to the piezoceramics natural hysteresis and the bonding layer between the piezoceramic and the thin plate of the bender element. The maximum hysteresis value is 13.5%. This value falls near the expected range for G-1195 piezoceramic of .1% to 10%.[1] This indicates that the bender element configuration is an efficient means of force conveyance. The linearity of the strut can also be inferred from Figure 4.[2]

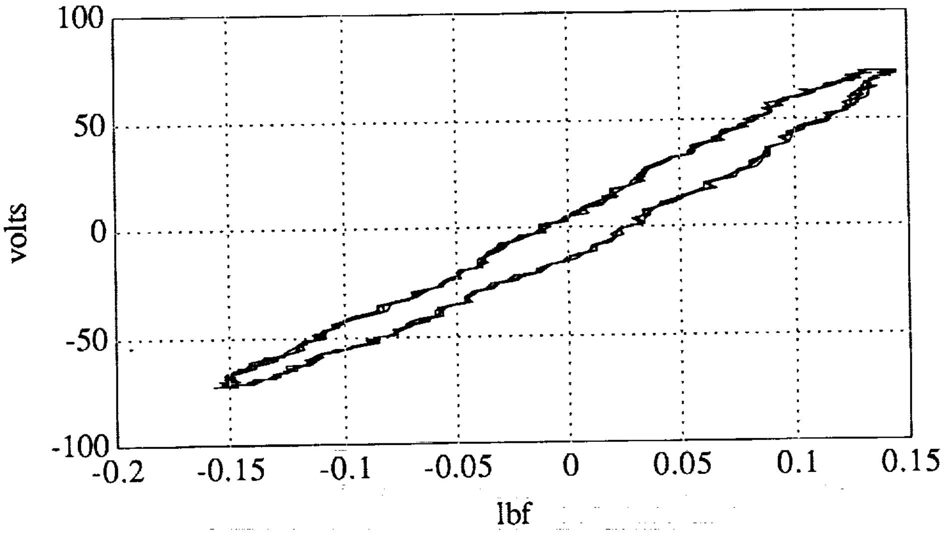

Figure 4. Force output and voltage input

A bode plot was constructed using a transfer function between the input voltage and the force output of the strut (Figure 5). The frequency of interest for the strut is approximately 0 to 100 Hertz; within this range the dynamic response of the strut is flat. The evolutionary model's first 85 modes are below 50 Hertz.[3]

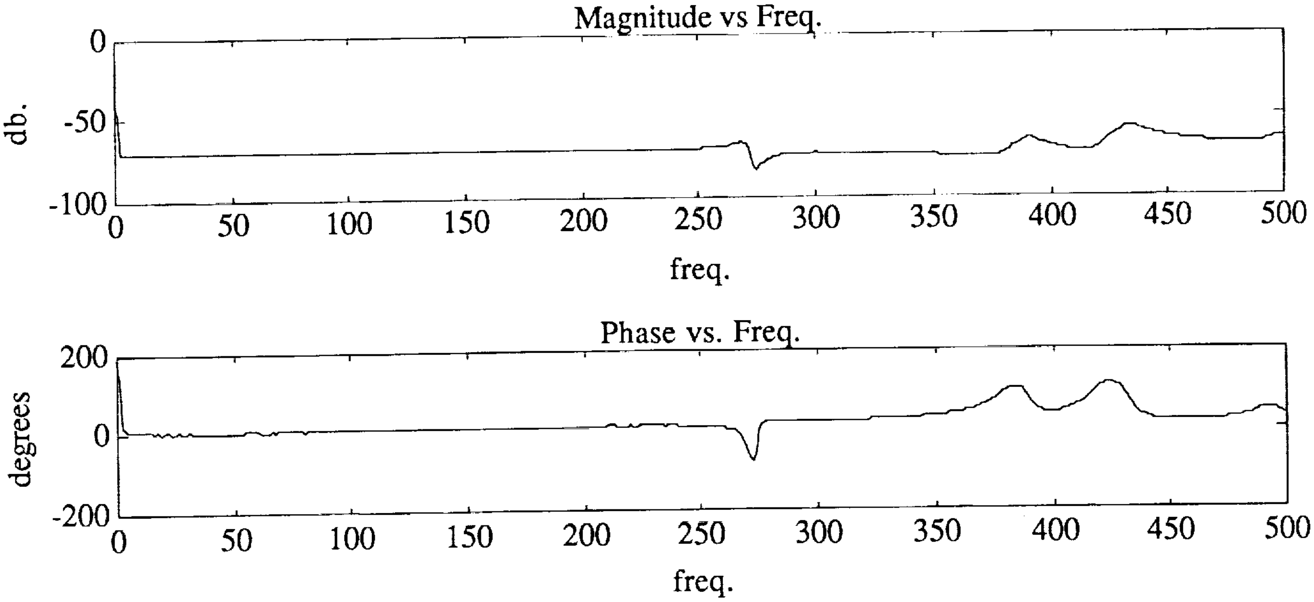

Figure 5. Dynamic response

In the second experiment a signal proportional to the regulated and measured force acting on the strut was input to the prototype strut. A 10 percent change in the stiffness was consistently recorded for forcing frequencies from 1 to 50 Hertz using the feedback scheme. The maximum displacement for this experiment was .0034". The results of a 5 Hertz signal is displayed in table II.

Table II. Experimental feedback results

Max total force (lbf)	Short circuit stiffness (lbf/in)	Feedback stiffness (lbf/in)
.55	6182	7011.18

FUTURE STRUT PARAMETERS

Using the strut in the evolutionary model would require a stiffness of approximately 100,000 lbf/in. By using this value, parameters can be established for a larger bender element strut. The results of this are listed in table III. The strut applies significantly less force than a more common piezoceramic stack type strut.[4] The reduced force ability may be offset by the greater stroke length of the bender element strut in some applications. It should be noted that the prototype geometrical dimensions are not optimal. Restraint on material availability prevented the construction of the optimal strut. Improvements in performance and efficiency may be achieved in a full scale strut.

Table III. Extrapolated strut results

Number bender elements	Stiffness (lbf/in)	Max. total force (lbf)
32	98912	17.6

SUMMARY

The static and dynamic characteristics of a new active replacement strut have been examined. The new strut type uses the bender elements in a series configuration to affect vibration suppression. This strut can be modelled using finite element methods. This strut has acceptable levels of hysteresis and linear characteristics. The dynamic response of the strut is flat for low frequencies, which is the range of operation and offers a viable alternative to the piezo stack struts commercially available.

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