

## ⚙️ Deflection-Compensating Beam for Use Inside a Cylinder

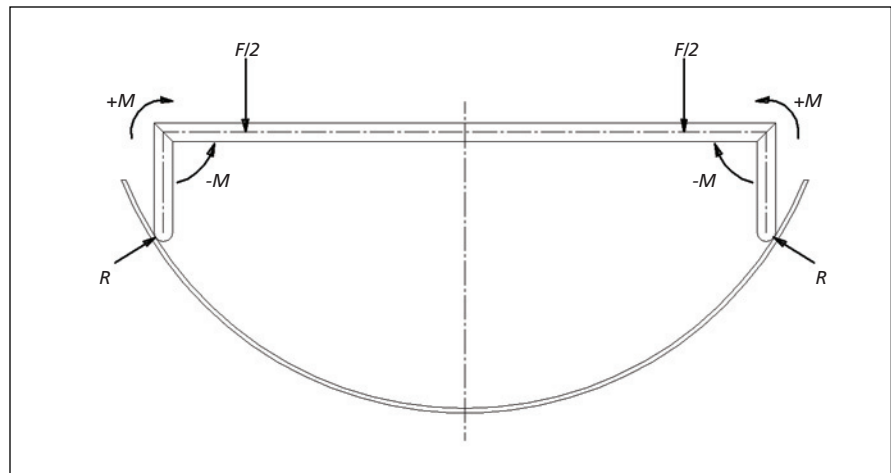
Deflections are minimized by combined effects of the beam and cylinder shapes.

Marshall Space Flight Center, Alabama

A design concept for a beam for a specific application permits variations and options for satisfying competing requirements to minimize certain deflections under load and to minimize the weight of the beam. In the specific application, the beam is required to serve as a motion-controlled structure for supporting a mirror for optical testing in the lower third portion of a horizontal, cylindrical vacuum chamber. The cylindrical shape of the chamber is fortuitous in that it can be (and is) utilized as an essential element of the deflection-minimizing design concept.

The beam is, more precisely, a tablelike structure comprising a nominally flat, horizontal portion with vertical legs at its ends (see figure). The weights of the beam and whatever components it supports are reacted by the contact forces between the lower ends of the legs and the inner cylindrical chamber wall. Whereas the bending moments arising from the weights contribute to a beam deflection that is concave (as viewed from above) with its lowest point at midlength, the bending moments generated by the contact forces acting on the legs contribute to a beam deflection that is convex (as viewed from above) with its highest point at midlength. In addition, the bending of the legs in response to the weights causes the lower ends of the legs to slide downward on the cylindrical wall.

By taking the standard beam-deflection equations, combining them with the geometric relationships among the legs and the horizontal portion of the beam, and treating the sliding as a component of deflection, it is possible to write an equation for the net vertical deflection as a function of the load and of position along the beam:



In this free-body diagram of a **Deflection-Compensating Beam**,  $F$  = applied force,  $M$  = resulting moment, and  $R$  = reaction force.

Total Deflection = (Deflection From Simple Support, Moment Load) + (Deflection From Simple Support, Twin Loads) + (Sliding at Wall)

The following is a summary of major conclusions drawn from the verbal characterization:

- The deflection at the point of application of a load cannot be made zero but it can be reduced, relative to the case of a simply supported beam of equal length.
- It is possible to obtain zero deflection at either the ends of the beam, the midlength point, or two points equidistant from the midlength point.
- The locations of the zero-deflection points are independent of the magnitude of the applied load. Moreover, if the beam and the legs are made of the same material and their cross sections are of the same size and shape, then the locations of the zero-deflection points are independent of the material and the cross sections.

- The maximum stresses occur at the ends of the horizontal portion of the beam.

Yet another advantage of the design concept arises from a fundamental geometric property. Just as a table having three legs of possibly unequal length can always rest on a horizontal surface without wobbling, a table having four legs of possibly unequal length can always rest on a cylindrical surface without wobbling. Hence, one can always be assured of realizing the desired geometry of contact between the beam and the cylindrical wall, and tolerances on leg lengths can be large. Hence, further, the cost of fabrication can be less than it would be if it were necessary to adhere to tight tolerances to ensure the desired geometry of contact.

*This work was done by Dwight Goodman, Neill Myers, and Kenneth Herren of Marshall Space Flight Center. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at [sammy.a.nabors@nasa.gov](mailto:sammy.a.nabors@nasa.gov). MFS-32123-1*

## ⚙️ Four-Point-Latching Microactuator

Fabrication is simplified and susceptibility to jamming greatly reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

Figure 1 depicts an experimental inchworm-type linear microactuator. This microactuator is a successor to the one described in "MEMS-Based Piezoelectric/Electrostatic Inchworm Actuator" (NPO-

30672), *NASA Tech Briefs*, Vol. 27, No. 6 (June 2003), page 68. Both actuators are based on the principle of using a piezoelectric transducer (PZT) operated in alternation with electrostatically actuated

clutches to cause a slider to move in small increments. However, the design of the present actuator incorporates several improvements over that of the previous one. The most readily apparent improvement

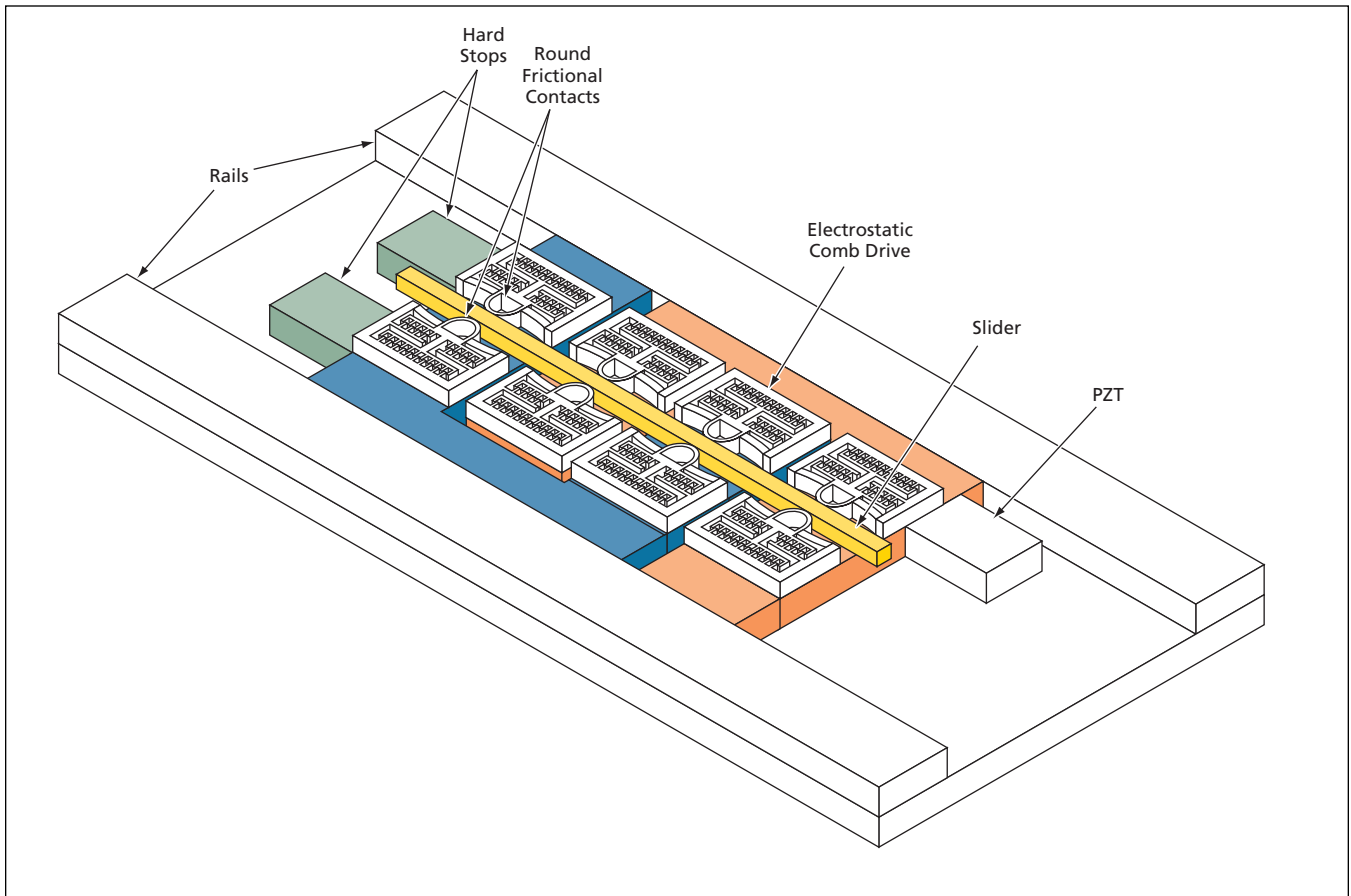


Figure 1. This **Four-Point-Latching Microactuator** features a predominantly planar geometric character and in-plane motion, in contradistinction to a prior microactuator having a more-complex three-dimensional character and perpendicular-to-the-plane motion.

is in geometry and, consequently, in fabrication: In the previous actuator, the inchworm motion was perpendicular to the broad faces of a flat silicon wafer on which the actuator was fabricated, and fabrication involved complex processes to form complex three-dimensional shapes in and on the wafer. In the present actuator, the inchworm motion is parallel to the broad faces of a wafer on which it is fabricated. The components needed to produce the in-plane motion are more nearly planar in character and, consequently, easier to fabricate. Other advantages of the present design are described below.

Whereas the previous actuator contained two clutches (denoted “holders” in the cited prior article), the present actuator contains four clutches. Each clutch includes a pair of units on opposite sides of a channel, into which the slider is inserted and along which the slider moves. Rails along the sides of the substrate prevent outward movement of the clutch units. Each clutch unit includes a rounded frictional contact that is spring-loaded against one side of the slider. Attached to each spring-loaded frictional contact is an electrostatic

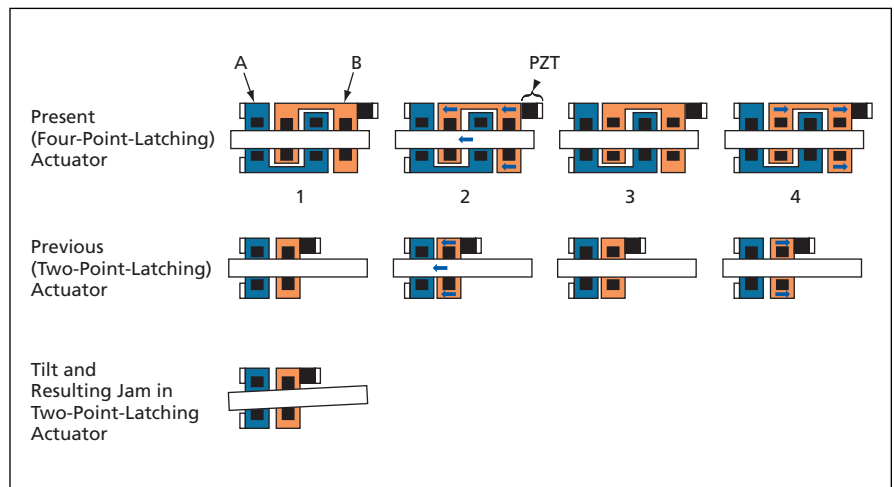


Figure 2. A **PZT and Clutches** are operated in alternation to produce small increments of motion of the slider along its long dimension. In the previous two-clutch actuator, the slider could tilt and become jammed.

comb drive that, when energized, opposes the spring load to pull the contact away from the slider. Hence, each clutch is normally latching: the rounded frictional contacts clamp the slider from opposite sides until and unless the electrostatic comb drives are energized. The spring load is obtained by inserting the slider that is slightly wider than fabri-

cated clutch clearance. This insertion also displaces the comb teeth to achieve very narrow ( $<1 \mu\text{m}$ ) comb gap that is power efficient but difficult to fabricate in bulk Si structure. A low-thermal-expansion-glass lid, omitted from the figure for the sake of clarity, is placed across the rails to retain the slider in the channel.

Figure 2 depicts the operation of the present and previous linear actuators and illustrates one of the advantages of the present actuator over the previous one. In the present actuator, the first and third clutches are operated in unison and are mounted on a stationary structure denoted A. The second and fourth clutches are operated in unison and are mounted on a moveable structure, denoted B, that can be driven a short distance forward or backward along the channel by a PZT. In step 1 of an operational sequence in which the slider is moved leftward, the clutches on unit A are released. In step 2, the PZT is extended to push unit B and the slider leftward. In step 3, the clutches on unit

A are latched while the clutches on unit B are released. In step 4, the PZT is retracted to bring unit B rightward. Repetition of steps 1 through 4 causes the slider to move leftward in repeated small increments.

The operational sequence of the previous two-clutch actuator is similar. However, the two-clutch configuration is susceptible to tilt of the slider and a consequent large increase in drag. Hence, the primary operational advantages of the present four-point-latching design over the prior two-point-latching design are less drag and greater control robustness arising from greater stability of the orientation of the slider.

*This work was done by Risaku Toda and Eui-Hyeok Yang of Caltech for NASA's Jet Propulsion Laboratory.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

*Innovative Technology Assets Management*

*JPL*

*Mail Stop 202-233*

*4800 Oak Grove Drive*

*Pasadena, CA 91109-8099*

*(818) 354-2240*

*E-mail: iaoffice@jpl.nasa.gov*

*Refer to NPO-42381, volume and number of this NASA Tech Briefs issue, and the page number.*

## Curved Piezoelectric Actuators for Stretching Optical Fibers

**Curved actuators produce greater displacements than do flat actuators.**

*Langley Research Center, Hampton, Virginia*

Assemblies containing curved piezoceramic fiber composite actuators have been invented as means of stretching optical fibers by amounts that depend on applied drive voltages. Piezoceramic fiber composite actuators are conventionally manufactured as sheets or ribbons that are flat and flexible, but can be made curved to obtain load-carrying ability and displacement greater than those obtainable from the flat versions. A curved actuator of this type can be fabricated by bonding a conventional flexible flat actuator to a thin metal backing sheet in a flat configuration at an elevated temperature so that upon cooling to room temperature, differential thermal contraction of the layers causes the laminate to become curved. Alternatively, such a curved actua-

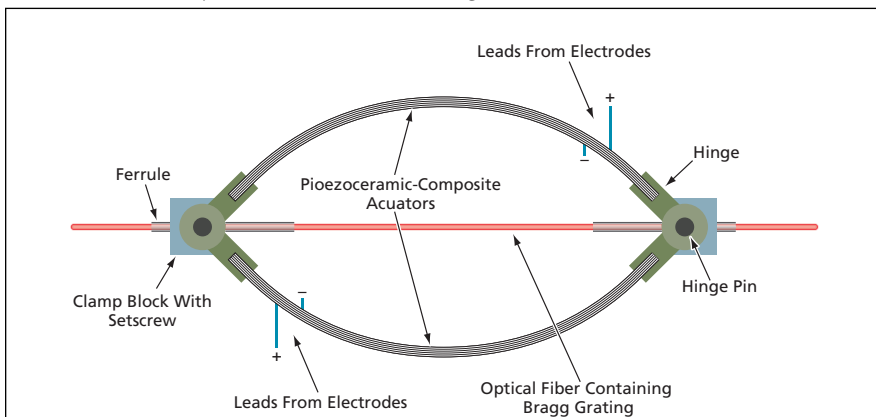
tor can be fabricated by bonding the layers together at room temperature using a curved mold.

In the primary embodiment of this invention, piezoceramic fibers are oriented parallel to the direction of longitudinal displacement of the actuators so that application of drive voltage causes the actuator to flatten, producing maximum motion. Actuator motion can be transmitted to the optical fiber by use of hinges and clamp blocks (see figure). Each clamp block includes a setscrew that tightens down onto a metal ferrule through which the optical fiber is bonded. Each hinge contains a clearance hole for a hinge pin, slots to accept the piezoceramic fiber composite actuators, and a clearance groove for the ferrule.

In the original application of this invention, the optical fiber contains a Bragg grating and the purpose of the controlled stretching of the fiber is to tune the grating as part of a small, lightweight, mode-hop-free, rapidly tunable laser for demodulating strain in Bragg-grating strain-measurement optical fibers attached to structures. The invention could also be used to apply controllable tensile force or displacement to an object other than an optical fiber.

Prior tunable lasers that are not fiber-optic lasers are relatively bulky and are limited to tuning frequencies of the order of 1 Hz. Tunable fiber-optic lasers could potentially be made much smaller, lighter in weight, and more rapidly tunable if strained by use of this invention. Prior actuators that could be used to strain-tune fiber-optic lasers or gratings include piezoelectric stacks that produce displacements smaller than those needed and that, in comparison with assemblies according to the present invention, are heavier. Displacements produced by piezoelectric stacks can be amplified mechanically, but the mechanisms needed to effect amplification add considerable weight, which can be unacceptable in aeronautical or aerospace applications because of the high per-unit-weight cost of flight.

*This work was done by Sidney G. Allison, Qamar A. Shams and Robert L. Fox of Langley Research Center. For further information, contact the Langley Innovative Partnerships Office at (757) 864-4015. LAR-17356-1*



**An Assembly Containing Two Curved Actuators** stretches an optical fiber by an amount that depends on the voltage applied to the electrodes.