



Robotic Arm Comprising Two Bending Segments

Thinness and multiple bending contribute to dexterity for operation in hitherto inaccessible places.

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The figure shows several aspects of an experimental robotic manipulator that includes a housing from which protrudes a tendril- or tentacle-like arm 1 cm thick and 1 m long. The arm con-

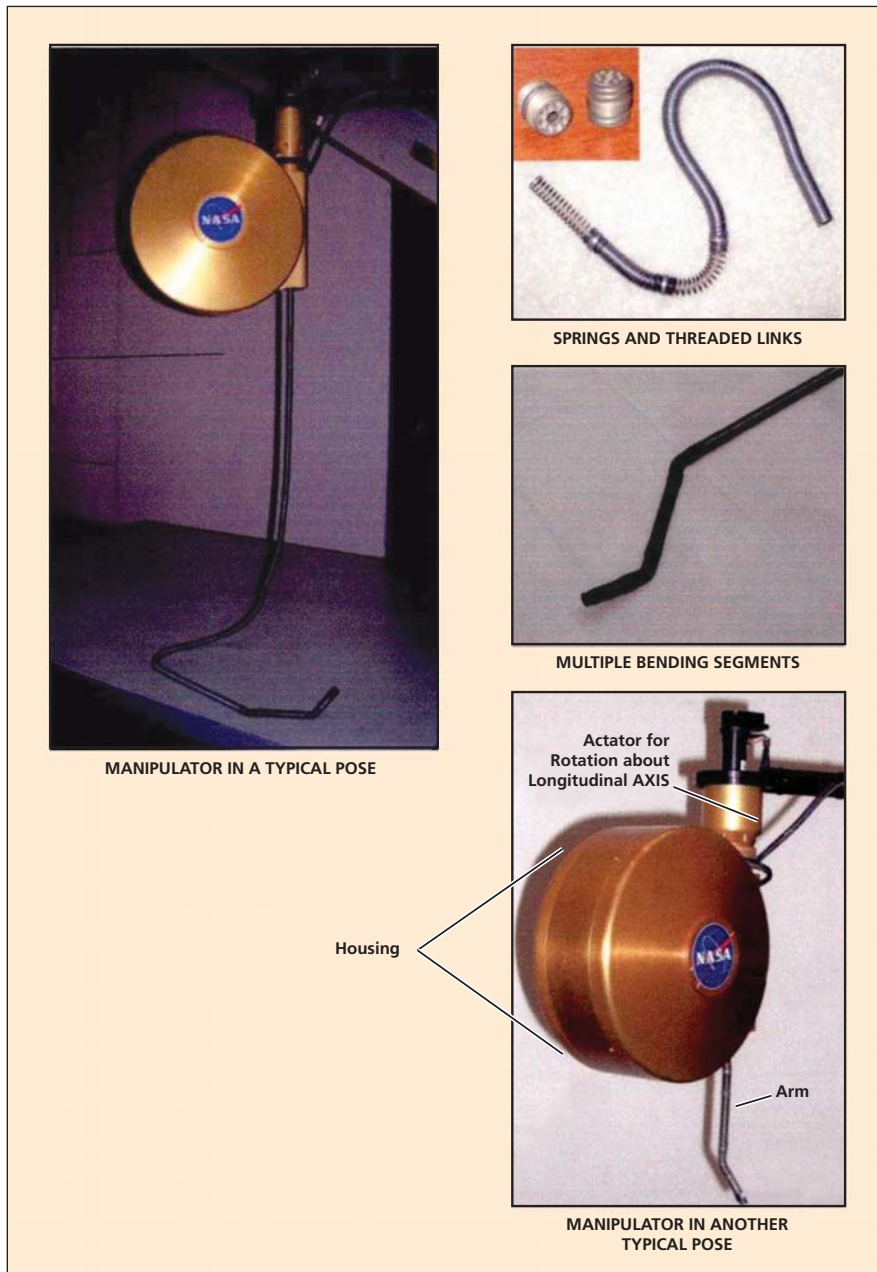
sists of two collinear segments, each of which can be bent independently of the other, and the two segments can be bent simultaneously in different planes. The arm can be retracted to a mini-

imum length or extended by any desired amount up to its full length. The arm can also be made to rotate about its own longitudinal axis.

Some prior experimental robotic manipulators include single-segment bendable arms. Those arms are thicker and shorter than the present one. The present robotic manipulator serves as a prototype of future manipulators that, by virtue of the slenderness and multiple-bending capability of their arms, are expected to have sufficient dexterity for operation within spaces that would otherwise be inaccessible. Such manipulators could be especially well suited as means of minimally invasive inspection during construction and maintenance activities.

Each of the two collinear bending arm segments is further subdivided into a series of collinear extension- and compression-type helical springs joined by threaded links. The extension springs occupy the majority of the length of the arm and engage passively in bending. The compression springs are used for actively controlled bending. Bending is effected by means of pairs of antagonistic tendons in the form of spectra gel spun polymer lines that are attached at specific threaded links and run the entire length of the arm inside the spring helix from the attachment links to motor-driven pulleys inside the housing. Two pairs of tendons, mounted in orthogonal planes that intersect along the longitudinal axis, are used to effect bending of each segment. The tendons for actuating the distal bending segment are in planes offset by an angle of 45° from those of the proximal bending segment: This configuration makes it possible to accommodate all eight tendons at the same diameter along the arm.

The threaded links have central bores through which power and video wires can be strung (1) from a charge-coupled-device camera mounted on the tip of the arms (2) back along the interior of the arm into the housing and then (3) from within the housing to an exter-



The Arm Extends From the Housing, which can be mounted on an actuator to effect rotation around the longitudinal axis of the arm. The housing has an outside diameter of 23 cm and a length of 13 cm along its cylindrical axis.

nal video monitor. Each link also contains guide holes for the tendons at equal angular intervals around the longitudinal axis.

The housing contains electronic control circuitry and the motors, pulleys, and other actuator mechanisms for effecting extension, retraction, and bending. For extension and retraction, the arm is wound on a motor-driven reel inside the housing. A spiral groove on the circumference of the reel guides the arm during extension or retraction and confines the arm to a single layer during multiple revolutions, so that a complex reeling mechanism is not necessary to prevent binding. The arm extends from

the reel out of the housing along a salient tube that is tangential to the reel. The salient tube also extends tangentially in the direction opposite that of the arm. This tube extension can be attached to a stationary fixture if rotation about the longitudinal axis is not desired. Alternatively, this tube extension can be attached to the output shaft of a stationary motor drive that can be used to effect rotation of the housing about the longitudinal axis of the tube, thereby effecting rotation of the arm about its longitudinal axis.

The system for controlling the pose of the arms is a standard position-control system based on a proportional + inte-

gral control loop, except as follows: the loop includes a washout filter (which is a special high-pass filter that, among other things, passes transient inputs while suppressing steady-state inputs) to take advantage of the inherent hysteretic friction of the tendon drive. The washout filter makes it possible to maintain a desired position by means of a small motor command aided by the inherent friction.

This work was done by Joshua S. Mehling, Myron A. Diffler, and Robert O. Ambrose of Johnson Space Center; Mars W. Chu of Metrica, Inc.; and Michael C. Valvo of Jacobs Sverdrup. Further information is contained in a TSP (see page 1). MSC-24128-1

Magnetostrictive Brake

Power demand would be reduced by 75 percent.

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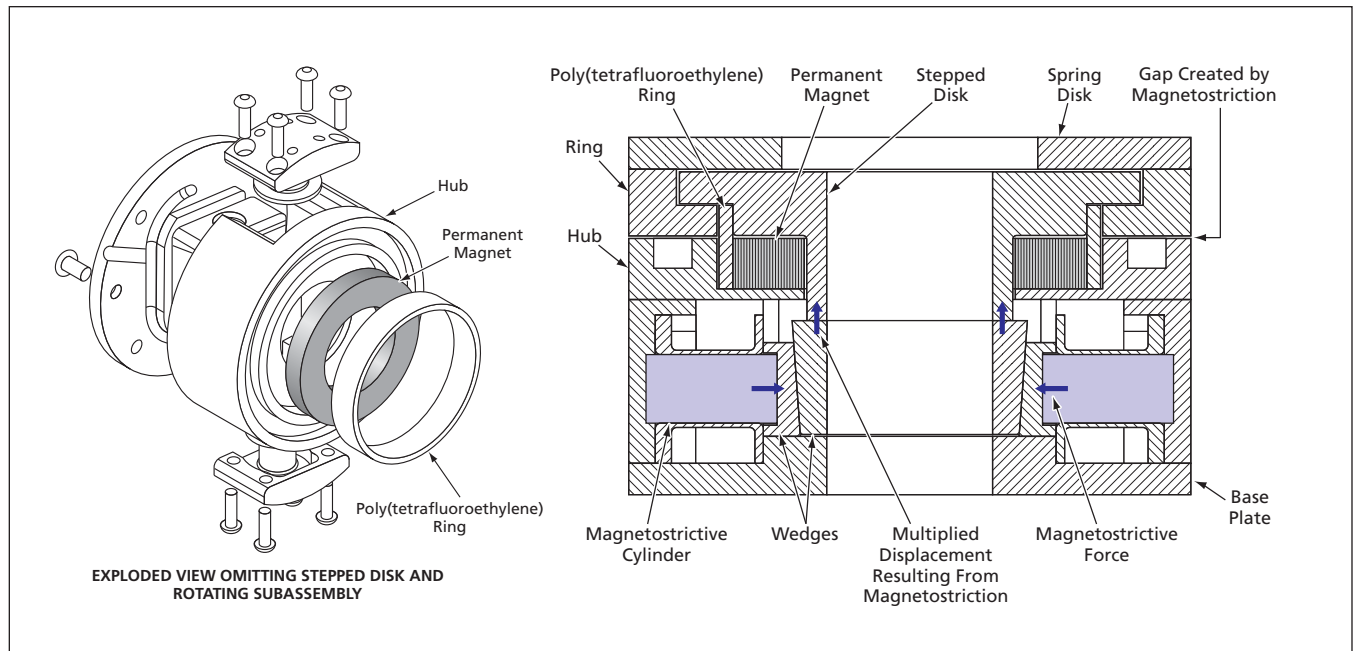
A magnetostrictive brake has been designed as a more energy-efficient alternative to a magnetic fail-safe brake in a robot. (In the specific application, “fail-safe” signifies that the brake is normally engaged; that is, power must be supplied to allow free rotation.) The magnetic fail-safe brake must be supplied with about 8 W of electric power to initiate and maintain disengagement. In contrast, the magnetostrictive brake, which would have about the same dimensions and the

same torque rating as those of the magnetic fail-safe brake, would demand only about 2 W of power for disengagement.

The brake (see figure) would include a stationary base plate and a hub mounted on the base plate. Two solenoid assemblies would be mounted in diametrically opposed recesses in the hub. The cores of the solenoids would be made of the magnetostrictive alloy Terfenol-D or equivalent. The rotating part of the brake would be a ring-and-

spring-disk subassembly. By means of leaf springs not shown in the figure, this subassembly would be coupled with the shaft that the brake is meant to restrain.

With no power supplied to the solenoids, a permanent magnet would pull axially on a stepped disk and on a shelf in the hub, causing the ring to be squeezed axially between the stepped disk and the hub. The friction associated with this axial squeeze would effect the braking action.



In the **Magnetostrictive Brake**, a large braking force would be generated by the permanent magnet. When power was supplied to electromagnet coils (not shown) surrounding the magnetostrictive cylinders in the solenoid assemblies, the resulting magnetostrictive strain would be converted to a force and displacement that would oppose the braking force.