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. Diftler, 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.

*Lyndon B. Johnson Space Center, Houston, Texas*

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, "failsafe" signifies that the brake is normally engaged; that is, power must be supplied to allow free rotation.) The magnetic failsafe 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.

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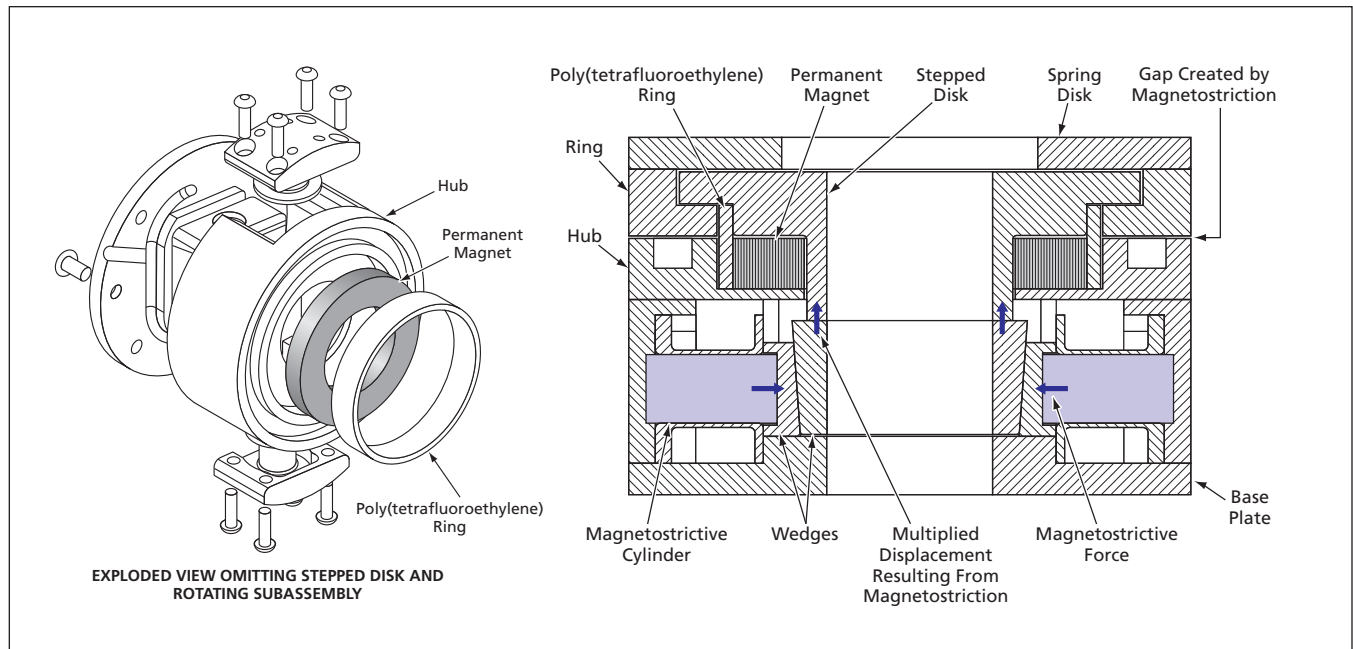
In the **Magnetostrictive Brake**, a large braking force would be generated by the permanent magnet. When power was supplied to electromagnet coils (not shown) surrounding the magnetostrictive cylinders in the solenoid assemblies, the resulting magnetostrictive strain would be converted to a force and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

Supplying electric power to the solenoids would cause the magnetostrictive cylinders to push radially inward against a set of wedges that would be in axial contact with the stepped disk. The wedges would convert the radial magnetostrictive strain to a multiplied axial displacement of the stepped disk. This axial displacement would be just large enough to lift the stepped disk, against the permanent magnetic force, out of contact with the ring. The ring would then be free to turn because it would no longer be squeezed axially between the stepped disk and the hub.

This work was done by Myron A. Diftler and Aaron Hulse of Lockheed Martin Corp. for Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-23629-1

✿ Low-Friction, Low-Profile, High-Moment Two-Axis Joint

This device can be utilized in robotics, automobile steering, transmission systems, and aircraft control surface linkages.

Lyndon B. Johnson Space Center, Houston, Texas

The two-axis joint is a mechanical device that provides two-degrees-of-freedom motion between connected components. A compact, moment-resistant, two-axis joint is used to connect an electromechanical actuator to its driven structural members. Due to the requirements of the overall mechanism, the joint has a low profile to fit within the allowable space, low friction, and high moment-reacting capability. The mechanical arrangement of this joint can withstand high moments when loads are applied. These features allow the joint to be used in tight spaces where a high load capability is required, as well as in applications where penetrating the mounting surface is not an option or where surface mounting is required.

The joint consists of one base, one clevis, one cap, two needle bearings, and a circular shim. The base of the joint is the housing (the base and the cap together), and is connected to the grounding structure via fasteners and a bolt pattern. Captive within the housing, between the base and the cap, are the rotating clevis and the needle bearings.

The clevis is attached to the mechanical system (linear actuator) via a pin. This pin, and the rotational movement of the clevis with respect to the housing, provides two rotational degrees of freedom.

The larger diameter flange of the clevis is sandwiched between a pair of needle bearings, one on each side of the flange. During the assembly of the two-axis joint, the circular shims are used to adjust the amount of preload that is applied to the needle bearings. The above arrangement enables the joint to handle high moments with minimal friction.

To achieve the high-moment capability within a low-profile joint, the use of "depth of engagement" (like that of a conventional rotating shaft) to react moment is replaced with planar engagement parallel to the mounting surface. The needle bearings with the clevis flange provide the surface area to react the clevis loads/moments into the joint housing while providing minimal friction during rotation. The diameter of the flange and the bearings can be increased to react higher loads and still maintain a compact surface mounting capability.

This type of joint can be used in a wide variety of mechanisms and mechanical systems. It is especially effective where precise, smooth, continuous motion is required. For example, the joint can be used at the end of a linear actuator that is required to extend and rotate simultaneously. The current design application is for use in a spacecraft docking-system capture mechanism. Other applications might include industrial robotic or assembly line apparatuses, positioning systems, or in the motion-based simulator industry that employs complex, multi-axis manipulators for various types of motions.

This work was done by James L. Lewis of Johnson Space Center and Thang Le and Monty B. Carroll of Lockheed Martin. Further information is contained in a TSP (see page 1).

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center, (281) 483-1003. Refer to MSC-23881-1.

✿ Foil Gas Thrust Bearings for High-Speed Turbomachinery

John H. Glenn Research Center, Cleveland, Ohio

A methodology has been developed for the design and construction of simple foil thrust bearings intended for parametric performance testing and low marginal costs, supporting continued development of oil-free turbomachinery. A bearing backing plate is first machined and surface-ground to produce flat and parallel faces. Partial-arc slots needed to retain the foil components are then machined into the plate by wire electrical discharge machining. Slot thicknesses achievable by a single wire pass are appropriate to accommodate the practical range of foil thicknesses, leaving a small clearance in this hinged joint to permit limited motion. The backing plate is constructed from a nickel-based superalloy (Inconel 718) to allow heat treatment of the entire assembled bearing, as well as to permit high-temperature operation. However, other dimensionally stable materials, such as precipitation-hardened stainless steel, can also be used for this component depending on application.

The top and bump foil blanks are cut from stacks of annealed Inconel X-750 foil by the same EDM process. The bump foil has several azimuthal slits separating it into five individual bump strips. This configuration allows for variable bump spacing, which helps to ac-