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A PRECISION ACTUATOR AND SHAFT ENCODER FOR A HIGH RADIATION ENVIRONMENT AND OTHER BEAM COMPONENT DEVELOPMENTS AT SLAC*

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Summary

A precision actuator and shaft encoder combination for remote handling in a high radiation and corrosive environment is described. The package allows accurate positioning of beam transport components in areas where liquid lubrication is not possible. The use of hexagonal lattice metals prevents galling or seizing of the rolling surfaces. The actuator translates rotary motion and torque supplied by a commercial radiation-resistant stepping motor into linear motion and force. Two actuators are in operation with a 7.5 cm output travel. Reproducibility is to ±1 step or 0.0015 cm. The shaft encoder resolves the turns of the motor in 1024 increments with cams and microswitches. The estimated dose rate of 10^{12} to 10^{13} ergs/g/yr in the vicinity of a SLAC high-power slit should present no problems.

The second part of the paper describes a new quick-disconnect injected indium vacuum seal. Indium is extruded into a gasket groove of a flange through tapped holes by means of bolts. Finally, a blowout fuse employed in the beam stoppers of the SLAC personnel protection system is described. The fuse responds to thermal radiation from the surface of a beam stopper by melting a low-temperature eutectic diaphragm thus letting the vacuum system up to air.

Introduction

The first generation of slits and collimators located in the SLAC beam switchyard has among other features a remotely controlled motorized jaw adjustment system, i.e., collimator and slit apertures can be opened and closed from the Data Assembly Building.[1] Each drive system consists of a screw jack actuator at the slit and a drive box (containing gear motor, encoder, potentiometer, microswitches, etc.) located in the upper tunnel housing for radiation protection. Motor and actuator are in some instances as much as 12 meters apart and linked together by a combination of drive shafts, miter gear boxes, and universal joints. While each of these drive systems has operated essentially flawlessly over the past five years, they were very expensive to design, fabricate and install. Furthermore, they limit the power absorber to a specific location and thus reduce operational flexibility. With these and other ideas in mind a new actuator and shaft encoder were developed.

The Actuator

A perspective view of the actuator is shown in Fig. 1. Extension and retraction is absolutely related to the relative rotation of two cylinders and can therefore be precisely

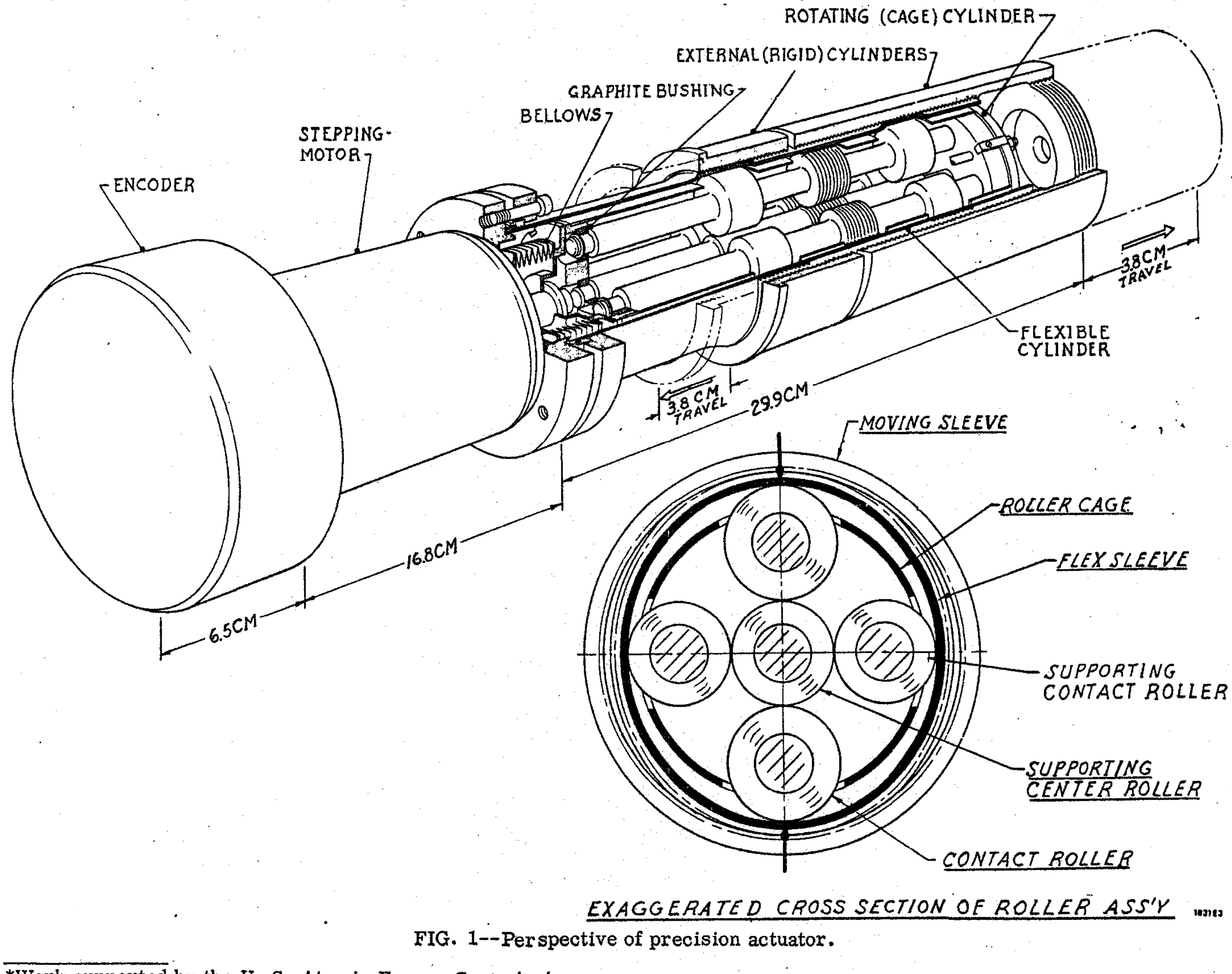

FIG. 1--Perspective of precision actuator.

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determined and relayed externally. The major force reduction occurs as a rolling engagement between double-pitch external threads on the surface of a flexible cylinder that is forced into an oval (elliptical) shape, and annular (not pitched) internal grooves in a rigid external cylinder. The external threads engage the annular grooves only near the major axis of the ellipse. Since there are two external cylinders and two sets of engaging pitched threads on the internal flexible cylinder, and since one thread set is left-handed and the other set right-handed, a rotation of the major elliptical axis by 360° relative to a point on the flexible cylinder itself will change the separation of the external cylinders (extend or retract) by precisely the pitch distance of four threads. The actuator might be called a "double linear harmonic drive".* The pitch length around the internal cylinder (ellipse) is shorter than that of the external cylinders. Thus, rotation of the major elliptical axis relative to itself results in a differential rotation between internal and external cylinders which is directly proportional to the differences in the internal and external pitch lengths. This is unimportant because the grooves in the external cylinders are annular and may therefore be engaged at any point around their periphery without changing extension or retraction of the external cylinders. Furthermore, because the pitch length differences of the two engagements are equal, the external cylinders do not rotate relative to each other.

The force is transmitted from one external cylinder across a thread engagement to the flexing cylinder, then through the flexing cylinder to and across the second thread engagement to the other external cylinder. There are just two loaded engagements at any one given time, and, as long as the thread height is not large relative to the thread diameter, the engagements are practically pure rolling.

The flexible sleeve is held oval at each thread engagement by a stack of three rollers (see "Exaggerated cross section" in Fig. 1). The sum of their diameters is slightly larger (0.07 cm) than that of the three rollers placed at 90°. Annular grooves on the surface of the center cam of each roller engage into annular grooves on the inside of the flexing sleeve and prevent axial motion of the rollers with respect to the flexing sleeve. All five rollers are guided by graphite bushings pressed into stainless steel discs. A roller cage cylinder with windows for the roller cams connects the two discs and keeps the axes of the five rollers parallel. This minimizes skewing of the rollers. If the flexible sleeve is sufficiently thin, its bending is entirely elastic and no work is required to rotate its axis of flexure.

Because the forces on the drive train are small, graphite on metal can be used for sliding pairs and the wear is small. The use of a hexagonal lattice structure metal allows dry operation[1,2] of a metal pair without pressure welding and with modest wear. Alpha-titanium alloy (Ti-5Aℓ-2.5 Sn) is used for the flexible sleeve and center roller; stainless steel for the external cylinders and outer rollers. An inorganic dry-lubricant can be used to further reduce friction and wear.

The extension or retraction of the actuator is determined by the relative rotation of the cage cylinder (with the five rollers) and the flexing sleeve. The prime mover must apply a torque between these two members. An electric stepping motor is used for this purpose. The motor frame is mounted to an extension of the flexing sleeve. The length and wall thickness of this extension was chosen such that the attachment to the motor frame does not flex. The motor shaft is joined to the rotating (cage) cylinder through a bellows coupling. This eliminates the need for precise centering.

The advantage of the stepping motor is that it produces a high torque and slow speed without gearing. It is commercially available in a "radiation-resistant" version† where the shaft is supported by polyphenyl ether-lubricated ball bearings. This oil is a useful lubricant for doses up to 10^{12} ergs/g.[3] For more severe radiation locations the ball bearings must be replaced with graphite sleeves. Another advantage of the stepping motor is that the residual magnetic fields prevent the shaft from turning when there is no pulsing current. The actuator has a very high efficiency and the applied force might be able to turn the motor were it not for this "magnetic detent".

The actuator was designed for 500 lbf load. Two units with a 7.5 cm stroke are now in use in the new high power B-Slit (SL-30) in the beam switchyard. However, the load is only 50 lbf in this application. A test to determine wear was made with a prototype. After 4050 cycles with a 200 lbf load and 10,000 cycles with a 50 lbf load no wear could be detected on a 100 power optical comparator. The stepping motor is capable of producing a torque of 25 lbf-ft; 18 lbf-ft were required to lift the 200 lbf load.

The Encoder

The encoder completes the drive package. It resolves the 24 turns of the stepping motor into 1024 increments. Figure 2 shows the encoder mounted.

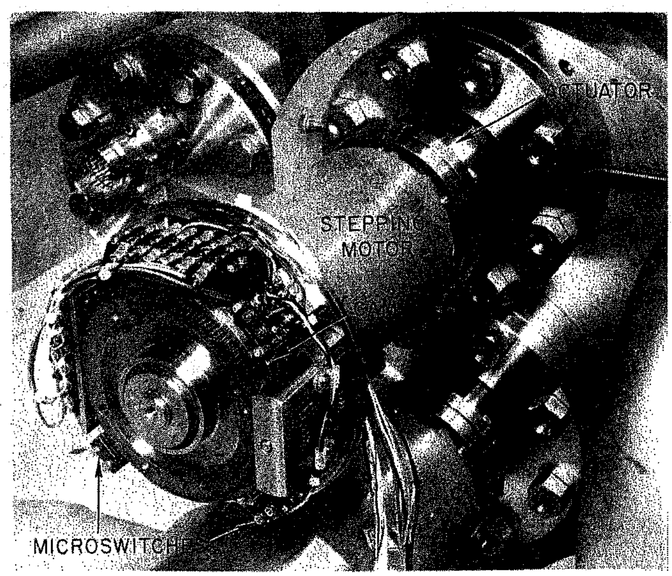

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FIG. 2--Shaft encoder.

The encoder is based on non-gray logic where each of four columns repeats at 90° intervals. This permits use of four cams, and microswitch stacks placed 90° apart around the cams in three locations. Only 10 switches are required to obtain 1024 bits (2^{10}). There is an eleventh switch which is doubled up with the last regular switch so they generate one count signal between them and also produce a blanking signal until all other switches have been actuated for a given count. For each stopping position there is a unique arrangement of closed and open switches.

Three of the cams rotate 8 times for the 24 turns of the stepping motor. The end cam rotates 1/8 turn intermittently; however, it rotates at the same speed as the other cams when it does turn. This gives the same switch resolution for all cams. The code is electronically converted to binary code. Reproducibility is to ±1 step or a mere 0.0015 cm. Since the mechanical output has zero backlash, this is the maximum indeterminancy per count.

All cams are stainless steel and are mounted on graphite bushings. The insulation on the wiring can be chosen according to the severity of the radiation environment.

*United Shoe Machinery Company.
†Superior Electric Company.

Injected Indium Vacuum Seal

Indium has been used for years as a sealant in vacuum gaskets because of its low vapor pressure (10^{-10} mm at 20^{o}C) and its low yield strength (380 psi). The latter permits small clamping forces. However, the continued cold-flow requires continuous follow-up for a seal to be maintained.

All of the compressed indium gaskets have one major disadvantage in that they must be stripped and reloaded with indium after the vacuum seal has been broken, in order to remake a dependable seal. This is not only costly but it often results in radiation exposure to maintenance personnel. In 1969, R. Sandkuhle (SLAC) showed the way to a dependable vacuum seal that essentially eliminated these problems. He demonstrated that indium can be extruded into a gasket groove by the simple procedure of putting a cylinder of indium into a tapped hole and tightening a bolt down into it. The extrusion pressures generated by this method are well over 20,000 psi and very little material extrudes back around the bolt.

The first application of the injected indium seal concept was on a 36 in ASA flange. The groove was 3/16 in × 3/16 in and the injection bolt spacing was 8 in. The indium had to extrude, therefore, 4 in each way. The flange bolts were 1-1/2 in - 6 UNC on about 4-1/4 in centers. The bolting on this flange was marginal for the forces imposed by the indium.

The next confirguration minimized the size of bolts by limiting the sealing width of the indium gasket to about 0.015 in. This 0.015 in wide groove joins a larger circumferential distribution cavity that is fed by the injection bolts. The circumferential pressure is more evenly distributed with this configuration. The bolting was reduced from 1-1/2 in to 5/8 in bolts on 4 in centers.

To further reduce the time to make or break the seal, new flanges will be clamped with quick-disconnect V-band couplings. Injection bolts will be 4-3/4 in apart. After initial loading of the groove, two turns of every other 3/8 in - 16 UNC injection bolt will pressurize the gasket and make the seal. Figure 3 shows a schematic cross section of the latest

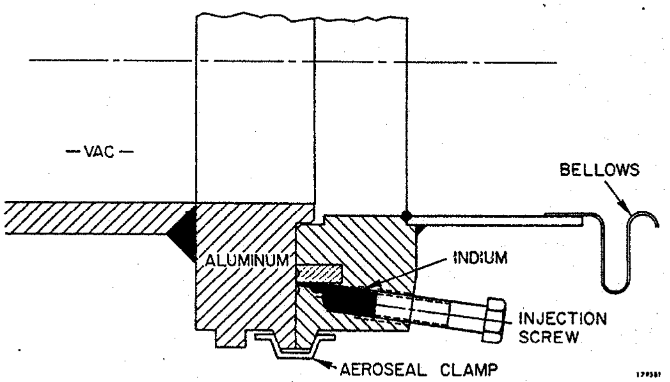

FIG. 3--Injected indium vacuum seal.

version of the injected indium vacuum seal. When the flanges are separated after prior pressurization, indium will extrude 1/16 in to 3/16 in out of the 0.015 in wide slot. This excess is shaved off with a plastic scraper before the flanges are reassembled.

The Blowout Fuse

The beam stoppers used as part of the personnel and equipment protection systems in the SLAC beam switchyard are 50 r.l., 10 cm diameter uncooled copper cylinders. Microswitches indicating the "in-beam" position prohibit delivery of the beam in this condition. Additional protection comes from an ionization chamber which turns the beam off after one pulse has impinged on the stopper. As a result of an accident with an equipment-protection beam stopper, where the "in" microswitches were not interlocked and the ion chamber failed, an additional safety feature was developed. Figure 4 shows a cross section of a "blowout fuse" or

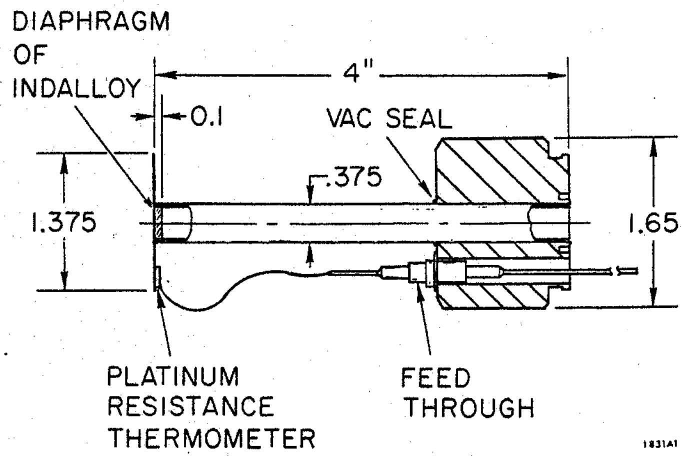

FIG. 4--Blowout fuse or thermal plug.

"thermal plug". The active part of the fuse is a diaphragm of a low-melting alloy cast into a thin-walled stainless steel tubing. Tests showed that a eutectic alloy was essential for reliable functioning of the device. The diaphragm separating the transport system vacuum from atmosphere is placed into the stopper vacuum chamber such that it opposes the stopper surface at close distance and at an axial location corresponding to the shower maximum of the electromagnetic cascade for SLAC beam energies. If a beam is accidentally impinged on a stopper, the surface temperature will rise fastest in the area of the shower maximum. Heat transfer by thermal radiation from the stopper will result in melting of the diaphragm, thus letting the vacuum system up to air. The beam is then shut off by a pressure switch in the vacuum system. This occurs at a time when there are still more than 40 radiation lengths of material in the beam path.

The eutectic fusible alloy selected is Indalloy* 136 which melts at 58^{o}C (an indium-lead-bismuth-tin alloy). A disc around the fuse acts as a heat collector and decreases the response time. A small platinum resistance thermometer is attached to the disc to give an early warning. It is also interlocked with the beam and turns it off at a temperature of 50^{o}C. A total of four fuses (two of which have thermometers) are installed in each stopper to provide redundancy. Fuses were successfully tested during beam operation at average beam powers of 27.5, 500 and 880 kW; and in one instance the fuses melted and turned the beam off due to excessively scattered radiation from a source other than the stopper.

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*Indium Corporation of America.