# A MOVABLE STOP MECHANISM FOR THE SIRE TELESCOPE

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## ABSTRACT

The purpose of the movable stop mechanism (MSM) is to activate flaps that change the size and shape of the telescope aperture stop on command. Operating at the cryogenic temperatures of the optical system, it consists primarily of a rotary solenoid that drives (activates) dual four-bar linkages in synchronism that in turn rotate the butterfly flaps into position. This paper discusses the design, performance characteristics, and test of this mechanism. Specific problems that occurred during test and the solutions that were adopted are also described.

## INTRODUCTION

The primary objective of the Space Infrared Experiment (SIRE) Program is to develop an infrared sensor system that can make a variety of star and space target measurements from space in several different spectral wavelength regions. During the course of this program, a requirement was added for a dual aperture stop configuration.

Figure 1a indicates the shape and size of the aperture stop during normal operation. The required alternate aperture stop configuration is shown in Figure 1b.

Hence the ability to change the stop from one configuration to the other is the general requirement for this mechanism. The movable stop mechanism (MSM) is pictured in its test fixture in Figures 2 and 3. Figure 2 shows the aperture stop with the flaps closed, and Figure 3 shows the drive solenoid that activates the flaps.

## DESIGN REQUIREMENTS

The principal design requirements for the MSM are listed in Table 1. The unique configuration restrictions and cryogenic optics application are the factors that govern these requirements.

### TABLE 1 - DESIGN REQUIREMENTS

- Operating temperature: $15^{o}$ to $25^{o}K$
- Power dissipation: ≤200 mW to close aperture stop and to keep it closed
- Power dissipation in open position: ≤10 mW
- Hold in closed position for at least five minutes
- Fail-safe in open position
- *Life: 5000 cycles minimum*
- Switches to indicate end-point positions
- Time to actuate: ≤1 second
- Noncontamination of cryogenic optics in vacuum
- Compatible with present telescope hardware

## DESCRIPTION OF MECHANISM

In the final design of the MSM, shown in Figure 4, the aperture stop and its actuating arm support bracket are made of beryllium. The arm, connecting links, link pins, and flap shafts are made of A-286 steel. The stop flaps are made of 6061 aluminum. The diameters of the journal-type bearing areas of the flap shafts and of the actuating arm shafts are sized to provide 0.015/0.025 mm (0.0006/0.0010 inch) of clearance in the respective mating pivot holes. The link pins are sized to provide 0.010/0.020 mm (0.0004/0.0008 inch) of diametral clearance in the respective mating pivot holes.

It was necessary to make several different-length configurations of the actuating arm and the No. 2 connecting link in length increments of 0.025 mm (0.001 inch) in order to be able to select parts at assembly to ensure symmetrical flap clearances in both the open and the closed positions. Adjustable stop screws are used to set the open and closed positions of the flaps.

The drive shaft connecting the solenoid output shaft to the actuating arm is made of A-286 steel and is designed to float axially in order to accommodate differential thermal expansion. The drive shaft also accommodates slight positional mislocations between the solenoid and the actuating arm.

Although the MSM is to operate in a zero-gravity environment, 1-g loading of contacting link and actuating arm surfaces can occur during ground tests because of the vertical orientation of the unit. To prevent the creation of excessive friction loads during test and during ground operation, Teflon washers are installed as shown in Figure 5.

The solenoid ball bearings and all shafts, link pins, stop flap shims, and pivot holes are coated with 99-percent-pure commercial lead lubricant, ion plated to a thickness of 2000/3000 Å. This lubricant was chosen because of its ability to meet the requirements imposed by operation in space at cryogenic temperature, low friction, and minimum contaminant generation.

The rotary solenoid is shown in Figure 6. The solenoid rotor is mounted on ball bearings in a titanium housing. The radial air gap between the rotor and pole pieces is 0.23/0.30 mm (0.009/0.012 inch). Each of the two pole pieces is wound with 1800 turns of 40-gauge magnet wire. Magnetic detent stops on the pole pieces reduce the air gap to zero at the closed position and thereby allow a reduction in the holding current needed. Redundant torsional springs made of beryllium-copper alloy are installed with an adjustable anchor post at the fixed end to permit the spring output torque to be accurately set. Reed switches indicate position, and in the closed position, the switch causes the actuating current (0.170 ampere) to be reduced to a holding current of 0.050/0.060 ampere. Reed switches housed in glass-filled polycarbonate resin were designed and built for this cryogenic application. A samarium-cobalt magnet attached to the rotor actuates these switches.

## PERFORMANCE CHARACTERISTICS

The measured performance characteristics of the MSM are shown in Figures 7 and 8.

Figure 7 is a plot of the measured activating torque delivered by the rotary solenoid versus angle as a function of the current in the solenoid coils. The solenoid is driven by a constant-current power supply that delivers a minimum current of 170 mA. The solenoid pole piece with a zero magnetic air gap in the actuated (closed) position allows a 66-percent reduction in the current needed to maintain closure. The closed position reed switch triggers this reduction in current.

Figure 8 is a plot of the measured torque needed to activate the MSM as a function of angle. The torque needed to overcome friction is approximately constant (15 gram-cm). Redundant return springs have been incorporated to ensure reliability. The spring design criteria were that the rotary solenoid should have a torque margin of 1.0 in order to close the stop when both springs were active; a margin of 1.0 to open the stop when one spring is inactive (broken) was also required. These requirements entailed a delicate balance that required spring adjustments during assembly and test.

## TESTING

The test plan originally adopted for the MSM provided for a 5000-cycle life test of an engineering model in a test dewar at a pressure of less than $10^{-4}$ Torr and at a temperature of less than 25°K. The test equipment provided for automatic cycling to close the movable stop, to maintain this position for 3 seconds, and to then release the stop to the open position for 1.5 seconds. The use of a manual override made it possible to keep the stop in the closed position for extended periods. At regular intervals during the test, the minimum actuating and minimum holding currents as well as the closing and opening times were measured in order to monitor changes in the performance characteristics of the MSM.

During the initial 5000-cycle test of the engineering model, unexplained stoppages occurred; although two subsequent 6000-cycle tests of this model were successfully completed, it was decided that a 20,000-cycle life test of both the engineering model and the flight unit should be conducted in order to establish confidence that this unit would be able to meet its 5000-cycle life requirement.

The refurbishment of the engineering model before this extended life test was begun consisted of relubricating all parts of the linkage with ion-plated lead. The 20,000-cycle life test of the engineering model was completed without failure. However, after the MSM had been brought up to room temperature at the conclusion of the test, the MSM was jammed in the open position, and the solenoid torque was insufficient to operate the linkage. During inspection, a slight pressure applied to one of the flaps released the stoppage, and the unit operated normally at room temperature thereafter. The engineering model was then subjected to an additional 6000-cycle test without failure; again, upon being brought to room temperature, it was jammed in the open position. Inspection established that except for the actuating arm, all parts of the MSM (i.e., solenoid, linkage, and flap shafts) were free to move. Further inspection disclosed that the area of contact between the actuating arm and the stop screws was galled or scuffed and that the line of action between this roughened contact and the pivot axis of the actuating arm could result in a locking force when differential thermal expansion between the steel actuating arm and the stop screws and the beryllium support bracket occurred during warmup. This situation is illustrated in Figure 9a. This stoppage was eliminated by modifying the angle of contact between the stop screw and the actuating arm stop contact surface and by applying a 0.050/0.076-mm (0.002/0.003-inch) coat of plasma-sprayed tungsten carbide to the stop contact surfaces of the actuating arm as shown in Figure 9b.

During the initial tests of the flight version of the MSM, stoppage occurred in the closed position after less than 500 cycles at operating temperature and pressure; however, at room temperature, it operated properly. Inspection of the solenoid revealed evidence of galling and of cold welding of the rotor to the magnetic detent stop of one of the pole pieces; see Figure 10. In a subsequent test of the engineering model, this same type of stoppage occurred after approximately 47,000 cycles. This marked discrepancy in the test results for the engineering model and those for the flight model was the result of differences in the electrical discharge machine tooling and in the different manufacturing setups used in fabricating these two models. As a result of these differences in manufacturing, the solenoid rotor for the flight unit struck a sharp corner of the pole piece magnetic detent stop and made contact with only one magnetic detent stop while the solenoid rotor for the engineering model made simultaneous flat contact with both pole piece magnetic stops (the Winchester Rifle 1-in-10,000 phenomenon). This stoppage was corrected by reworking the pole piece magnetic detent stops to eliminate the possibility of sharp corner contact and to bring the rotor into simultaneous contact with both pole piece magnetic detent stops. In addition to this rework, the solenoid rotor contact area was coated with a 0.050/0.076-mm (0.002/0.003-inch) layer of plasma-sprayed tungsten carbide. This coating increased the minimum holding current from 0.013 to 0.027 ampere.

During continued testing of the MSM flight unit, stoppages occurred in the open and in the partially open positions at operating temperature and pressure; however, at room temperature, the unit operated normally. Careful comparison of the engineering model with the flight unit revealed a slight difference in the diametral clearances between the shafts and the holes. Because of rework on the engineering model, these clearances were 0.0025/0.005 mm (0.0001/0.0002 inch) greater than the drawing tolerance that the flight unit met. The drawings were changed, and the flight unit shaft diameters were reworked to provide the 0.015/0.025-mm (0.0006/0.0010-inch) clearances that characterized the engineering model.

A problem related to the maintenance of end play on the flap shafts was also encountered; see Figure 11. In the engineering model, the flap was keyed to the flap shaft by means of a coiled spring pin. Apparently, the friction between the pin and the flap slot maintained the axial position of the flap on its shaft and thereby ensured that the amount of end play set during assembly was maintained. During the design review, the use of the coiled spring pin was criticized; the attachment of the flap shaft was therefore redesigned. A flattened shaft, a flat-sided hole, and a retaining ring were substituted. The flap can now shift on the shaft in a way that tends to eliminate the shaft end play established at assembly. The attachment of the flight unit flap shaft to the flap was redesigned to incorporate an additional retaining ring and thereby ensure the maintenance of the proper shaft end play.

With these changes in the shaft-to-hole diametral clearances and in the flap-to-flap shaft attachment, the MSM flight unit successfully completed the 20,000-cycle life test.

## CONCLUSIONS

Testing an engineering model is useful in debugging the initial design and test procedures for any mechanism that must meet stringent requirements for low friction, close tolerances, and precise balancing of the spring output torque against solenoid output torque. However, each subsequent mechanism assembly must be subjected to a level of testing that will demonstrate that assembly parameters relating to friction, tolerances, and spring/solenoid output torque balance have been satisfied.

The activating current needed to close the MSM exceeds the power dissipation design requirement (465 versus 200 mW), but the current is used for less than 0.1 second and is then reduced to a holding current which dissipates only 40 mW during the rest of the operating cycle, which may last for 5 minutes or more. It is therefore believed that the 200-mW maximum power dissipation requirement has been met. Estimates of reliability based on the life-cycle tests predict that the MSM and the solenoid will meet the 5000-cycle life requirement. All other design requirements were demonstrably met.

The ion-plated lead lubrication has proved to be satisfactory for a lightly loaded journal bearing type of application at cryogenic temperature and in a vacuum.

The tungsten carbide coating was effective in preventing galling and cold welding of the contacting surfaces in the presence of significant impact forces.

The importance of exactly replicating the fits, geometry, and assembly parameters of the engineering models in the subsequent production of flight units has once again been very positively demonstrated.

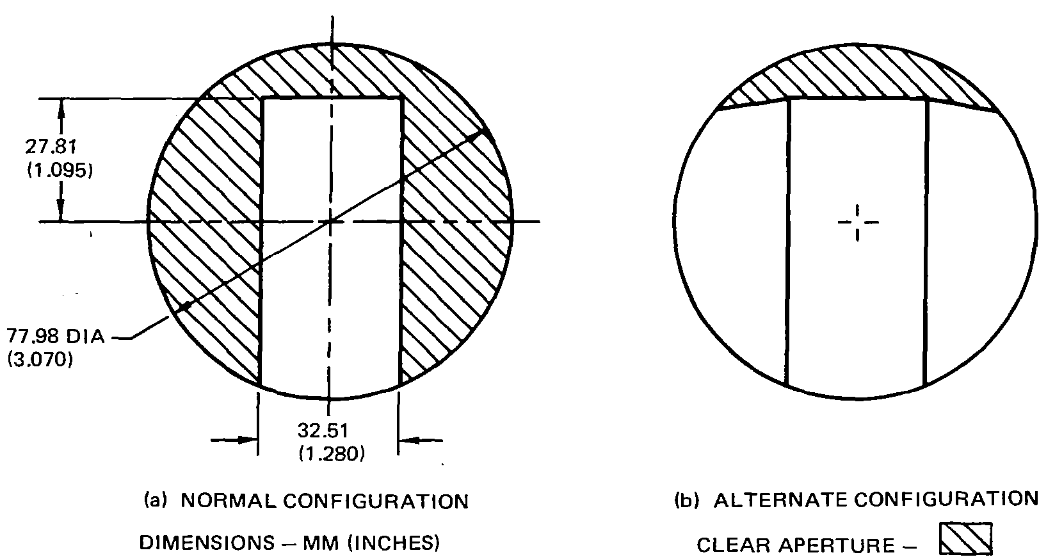


Figure 1. Aperture stop configurations.

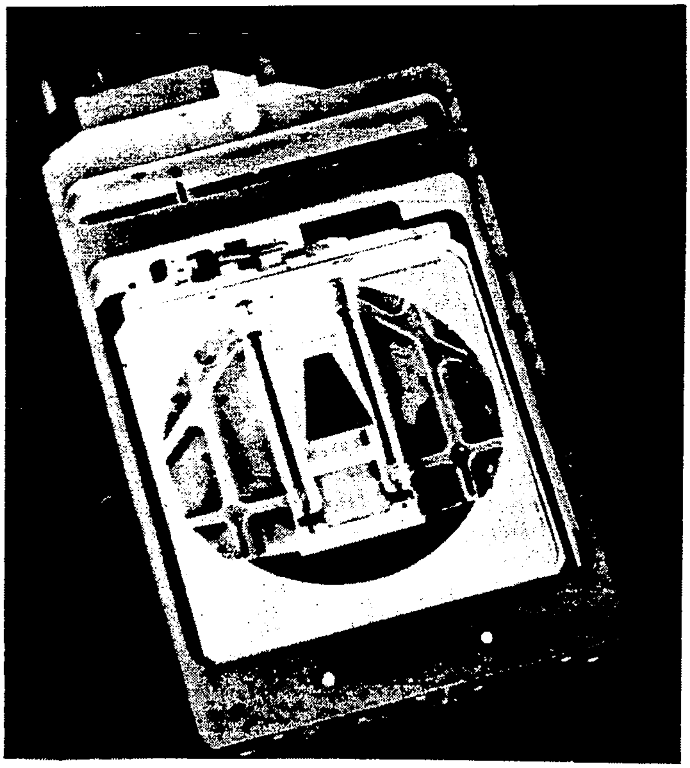

Figure 2. MSM with flaps closed.

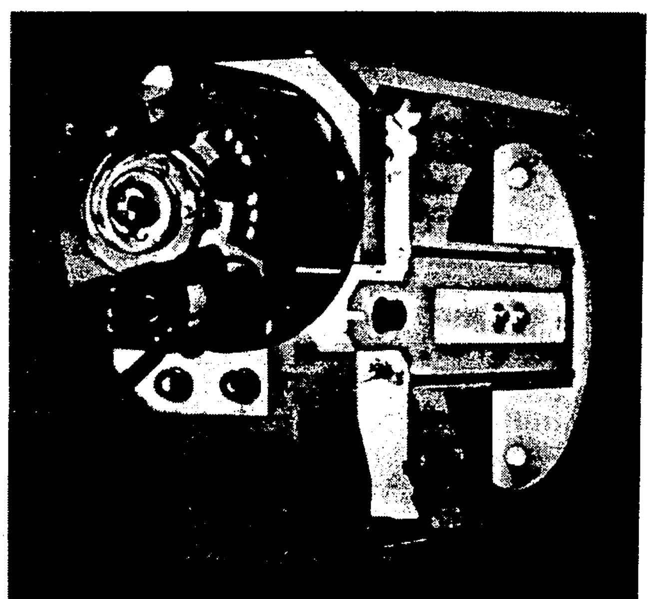

Figure 3. MSM drive solenoid.

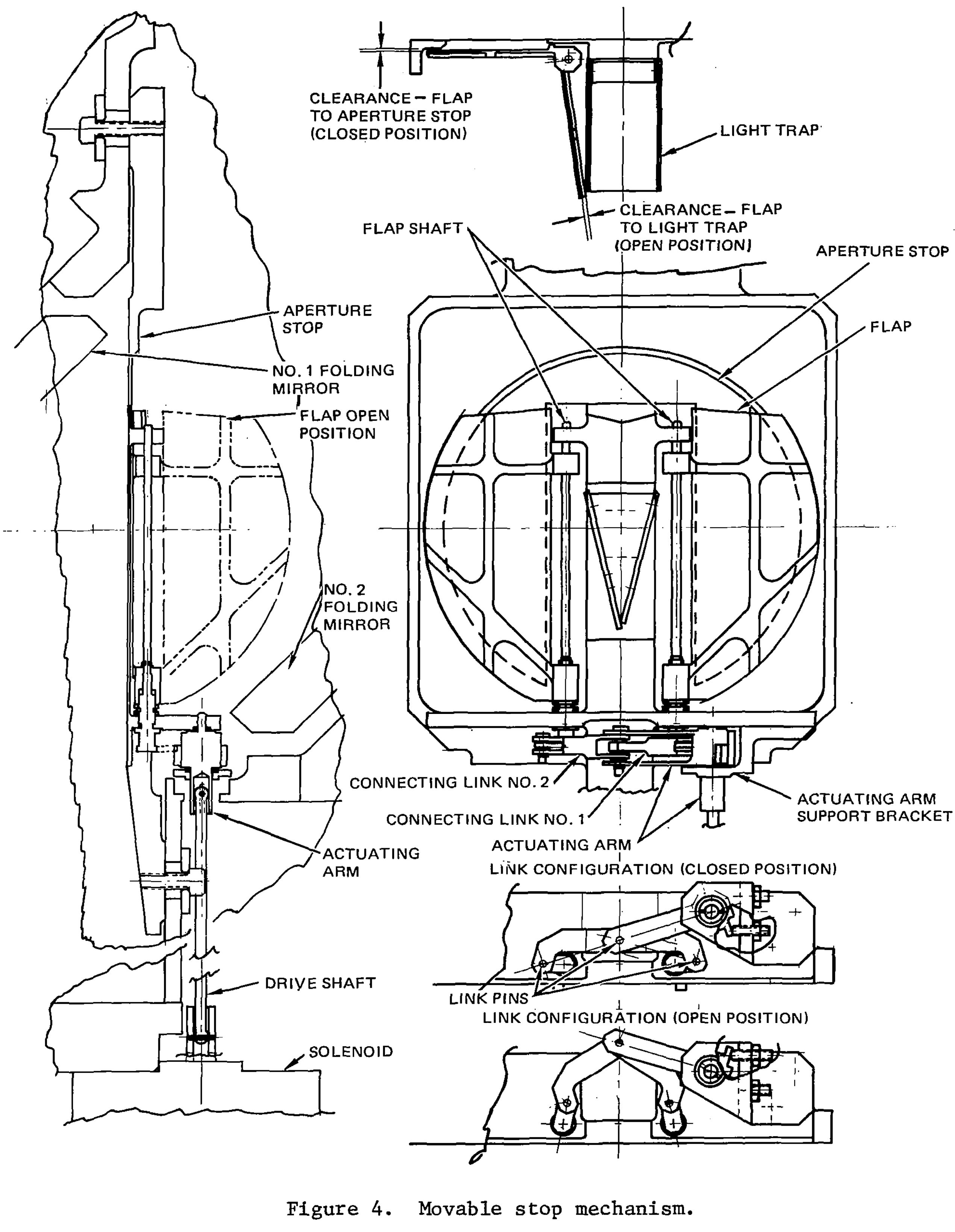


Figure 4. Movable stop mechanism.

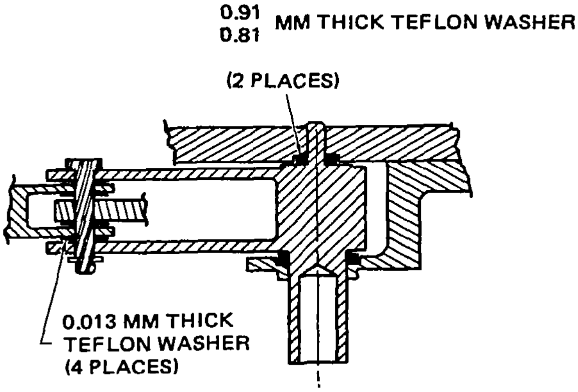


Figure 5. Teflon washer installation.

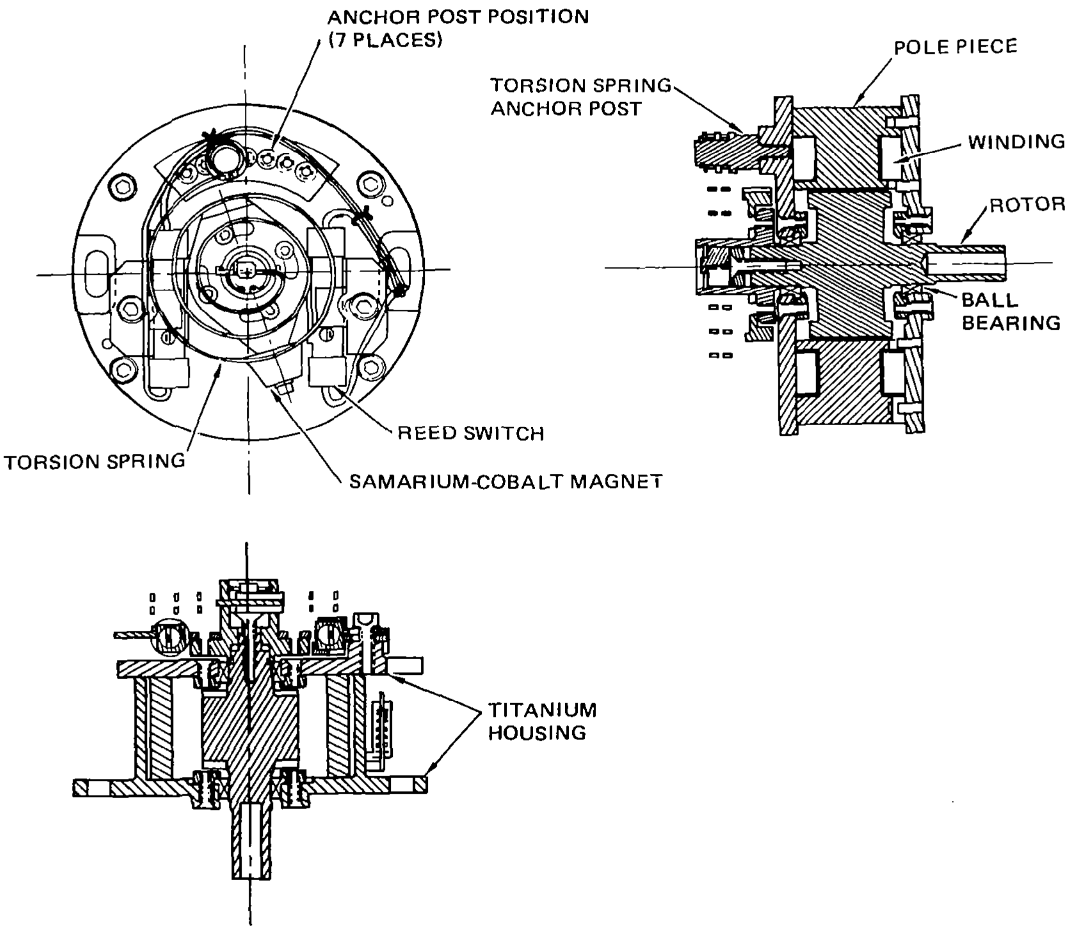


Figure 6. Rotary solenoid.

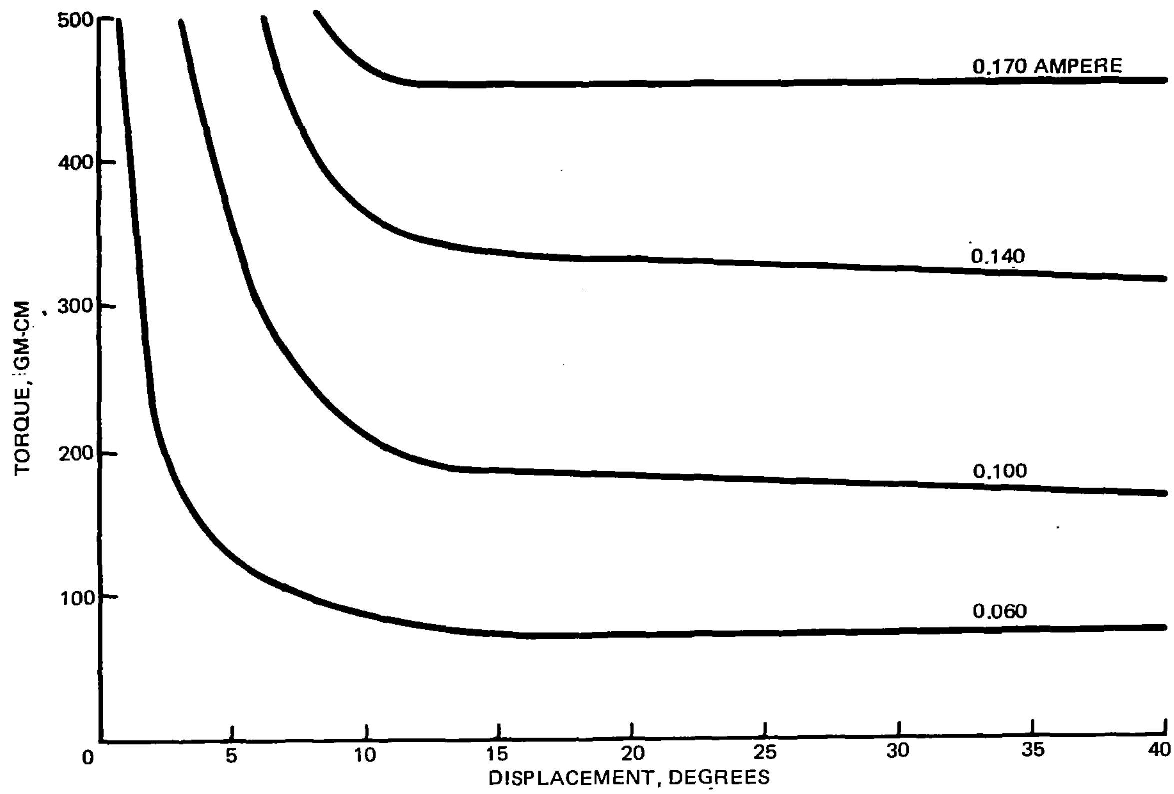


Figure 7. Measured solenoid output torque.

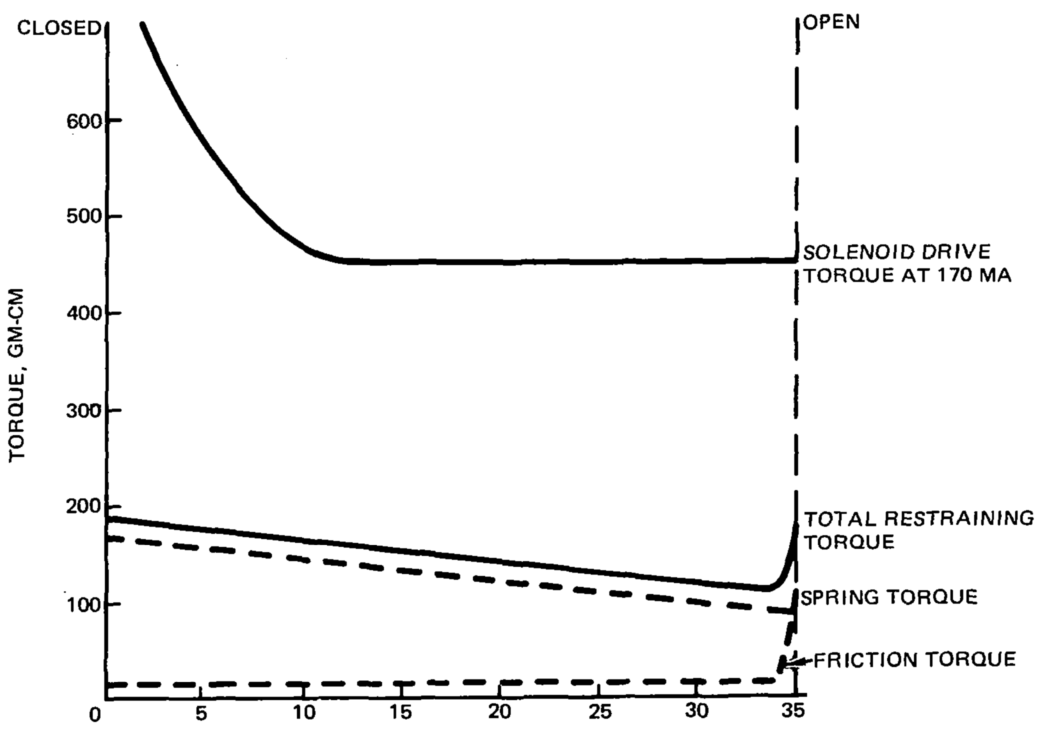


Figure 8. Measured performance at room temperature.

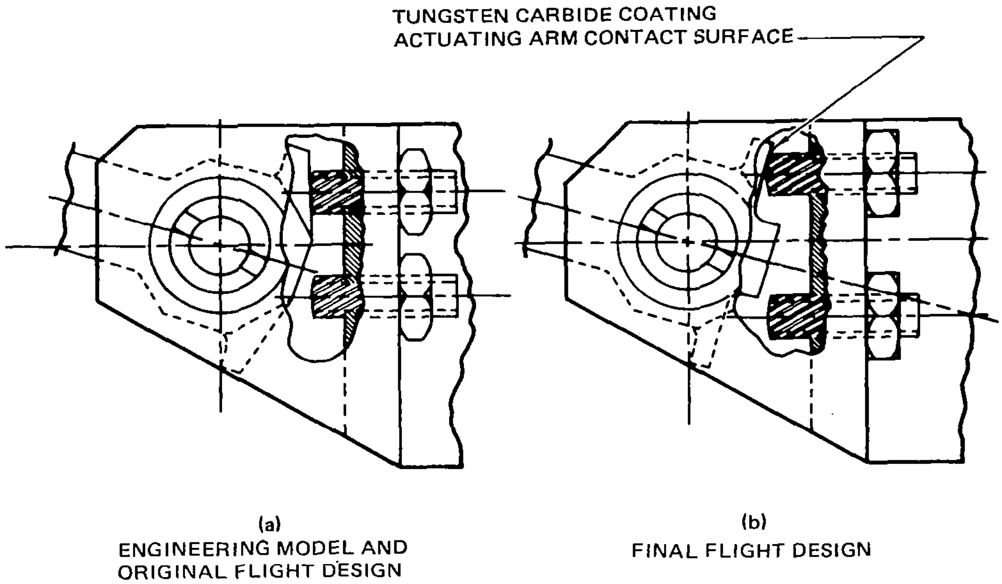


Figure 9. Actuating arm stop contact surfaces.

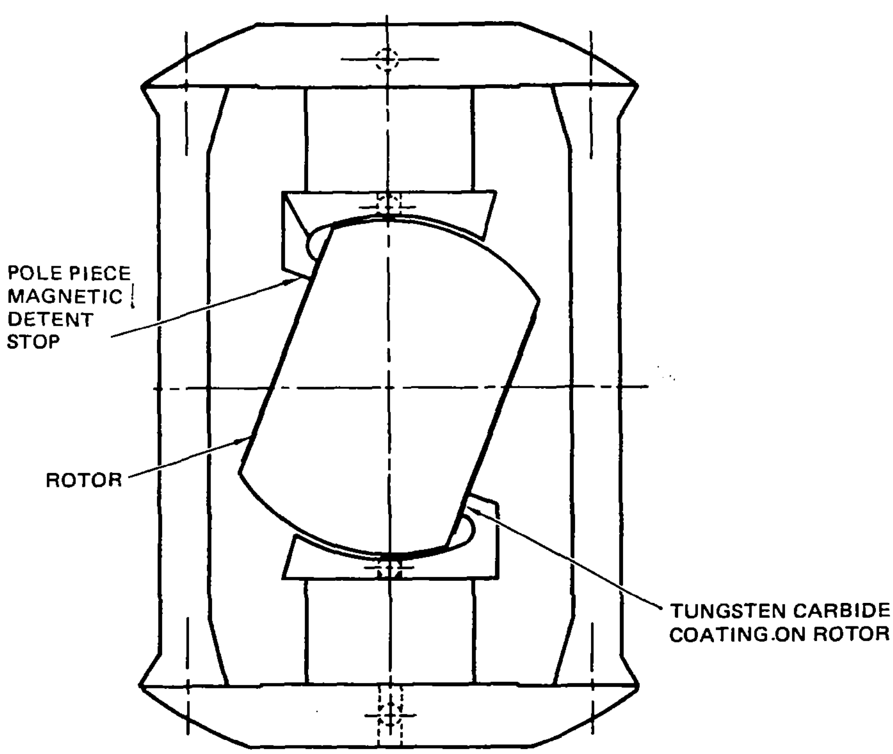


Figure 10. Solenoid rotor/pole piece contact.

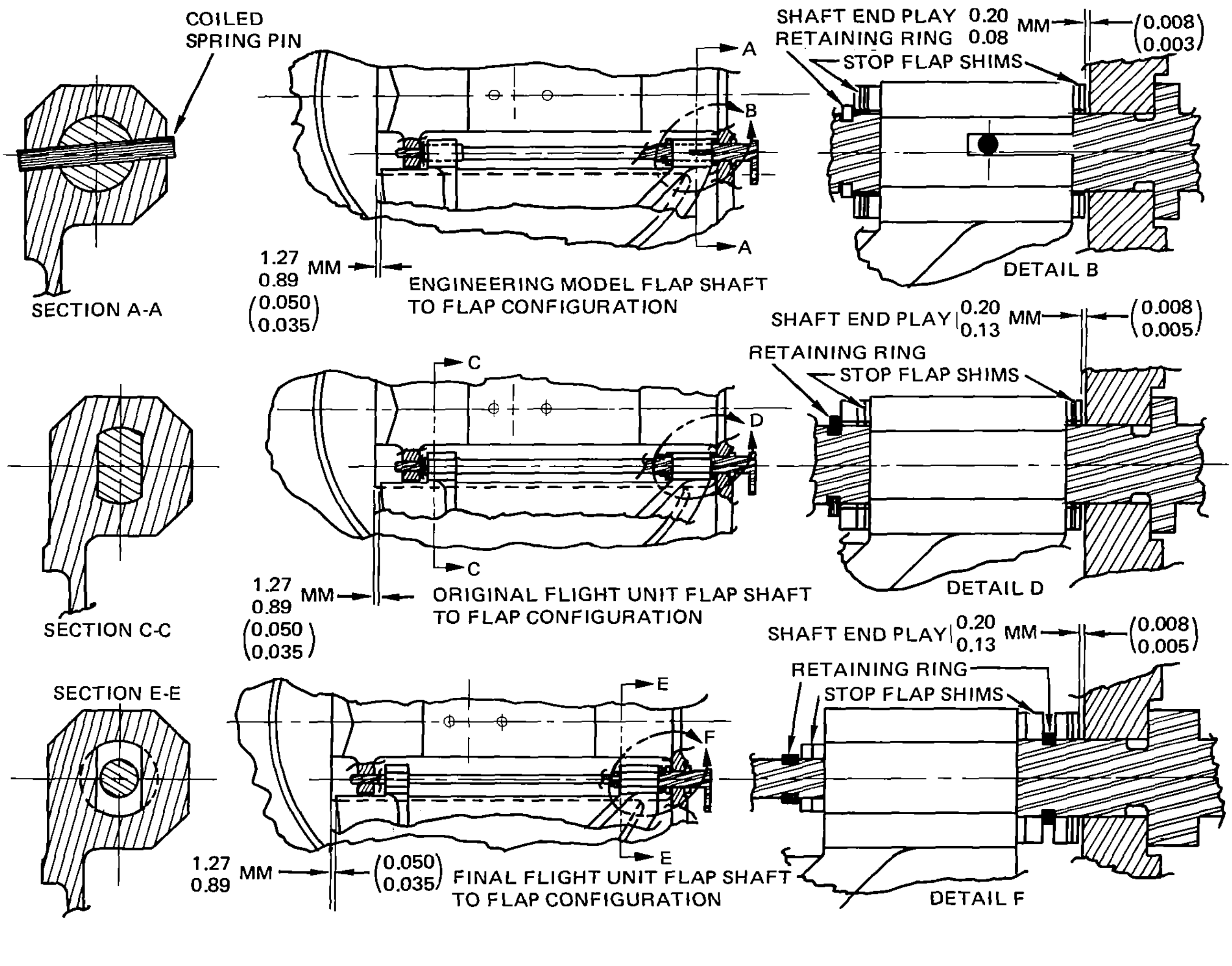


Figure 11. Flap shaft to flap configurations.

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