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14. A NEW CONCEPT FOR ACTUATING SPACE MECHANISMS

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SUMMARY

A two-position (0° and 180°) actuating mechanism driven by two alternately-heated opposing flat NITINOL springs is proposed for rotating the low field triaxial fluxgate magnetometer experiment on the 1977 Mariner Jupiter-Saturn spacecraft to its 0° and 180° positions. The magnetic field, power requirements, weight and, and volume of this device are very restrictive. The problems encountered in design and development of this device are presented.

INTRODUCTION

The purpose of this experiment is to provide precise, accurate, and rapid vector measurements (from 0.01 γ to 20 gauss, $1\gamma = 10^{-5}$ gauss) of the magnetic fields of Jupiter and Saturn in interplanetary space to them and beyond. These data extend in situ studies of the solar wind interaction with Jupiter and characteristics of its magnetic field and yield first studies of Saturn's field and its interactions if the solar wind extends to 10 AU.

Performing accurate measurements of magnetic fields on a spacecraft not fabricated magnetically clean is a major problem. A moderately long boom will be used to place two low-field($\leq$6400 γ) triaxial fluxgate magnetometers at remote distances from the spacecraft. Simultaneous measurements will yield separate estimates of the spacecraft field and the ambient field.

The purpose of this essentially nonmagnetic actuator is in-flight calibration of the triaxial fluxgate magnetometers. This calibration, which determines the sensor zero point, is accomplished by periodically flipping the magnetometers by 180 degrees.

The advantages of this mechanism are that it satisfies more than any other known device, the constraints of volume, weight, nonmagnetic materials, and power in relation to the requirements of high torque, fast cycling and long life. These properties are derived solely from the unique mechanical qualities of 55-NITINOL. This actuator will provide cyclical bi-directional rotary motion under varying environmental temperatures (-45°C to +40°C) in a vacuum for periods up to five years.

This paper describes the mechanical and electrical functions of the design which evolved, as well as the problems encountered. The objectives achieved are evaluated and other possible applications are presented.

OBJECTIVE

The objective was to develop an actuator which would meet the following requirements.

1. Rotate 180 degrees ± 15 minutes of arc.

2. Remain at the indexing stop until again actuated.

3. Have a permanent magnetic field (when not being powered) less than 0.1 γ at 2.54 cm (1 in).

4. Have a minimum capability of 300 cycles during a period of five years.

5. Complete the rotational indexing within 30 seconds of initiation.

6. Require not more than 8 watts of power for less than 30 seconds.

7. Weigh less than 0.227 kg (0.5 lb).

8. Fail-safe indexing, i.e., the actuator must not stop in any position other than 0 or 180 degrees.

9. Operate within the temperature range of -45°C to +40°C.

10. Operate in a vacuum.

DESIGN

The selection of a design approach required the consideration of other feasible concepts. Among those reviewed were bimorph piezoelectric devices, opposing coil solenoids (without cores), nonmagnetic electric motors, Freon state conversion bellows, and wax pellet actuators.

A concept utilizing 55-NITINOL was adopted because it appears to most reliably meet the above design requirements.

55-NITINOL

About ten years ago, Buehler and Wiley of the U. S. Naval Ordnance Laboratory developed a special purpose nickel-titanium alloy (55-NITINOL) that possesses "mechanical memory" (see reference 1). The phenomenon is caused by a thermally induced atomic shear transformation which occurs in 55-NITINOL. The salient property of this alloy is its memory of shapes imposed on it at a characteristic "annealing" temperature T_a. This effect is manifested, after return to an arbitrary lower temperature T_1 at which plastic deformation ($\leq 8\%$ strain, fig. 1) has been induced, by its forceful return to the originally imparted shape (at T_a) following heating to the transition temperature T_t ($T_1 < T_t < T_a$). Simply stated, this means that any shape formed at the "annealing" temperature can be thermally induced to reoccur in spite of deformations ($\leq 8\%$ strain) imposed at lower temperatures.

The 55-NITINOL used in this mechanism has a T_a = 500°C and T_t = 80°C. The transition temperature T_t is a function of material composition and cold working and can range from -100°C to +300°C. The onset of restoring stress (memory) is not sharply defined (figs. 1 and 2), rather T_t is a temperature range ($\approx$10°) over which the restoring stress increases by a factor of four and the modulus by a factor of four, as illustrated in fig. 2. If the 55-NITINOL flat springs were unrestrained they would assume the shape of a straight strip (memory shape) at 90°C (upper T_t range). The spring torque of this actuator varies directly with the yield stress of the NITINOL which is solely dependent on whether its temperature is above or below the transition temperature range. The springs used in this test model will provide 0.029 kg-m (40 in-oz) of gross torque. After about 1,000 cycles the gross torque output should level off at about 95% of the initial value.

MECHANICAL OPERATION

The mechanism as shown in figs. 3 and 4 is simply an experiment container which can be bi-directionally rotated by two opposing NITINOL flat springs with bonded heater strips, whose indexing is biased by two over-center Flexator springs. To operate the actuator, the appropriate NITINOL spring (fig. 3, section A-A) is heated to its transition temperature range (+80°C to +90°C), increasing the modulus of elasticity from 27.6×10^6 N/m^2 to 82.7×10^6 N/m^2 (4,000,000 psi to 12,000,000 psi) (fig. 2), providing a torque greater than the unheated spring. This action drives the toggled spring crank (figs. 3 and 4) and the pinned crank arm clockwise from the position shown. After 90 degrees rotation, the two Flexator springs drive the crank arm, fail safe, to the opposing stop, 180 degrees from where it started. The shaft rotates the experiment in its container and acknowledges the indexing through a cam-actuated microswitch as shown in fig. 3. When the heater is turned off by telemetry and the NITINOL spring falls below the transition temperature, the crank arm is held against the indexing stop by the two Flexator springs. The rotation is reversed by applying electrical power to the heater strip which is bonded to the NITINOL flat spring shown in section A-A, fig. 3. This drives the crank arm counter clockwise back to where it started.

MATERIALS

The prime considerations in the selection of materials for this mechanism were low magnetic permeability (< 1.001), volume and weight. The Flexator springs were made of Elgiloy, the bushings, housing and experiment container from Delrin, and the shafts and other hardware from titanium alloy, beryllium copper, aluminum and brass.

ALTERNATIVE USES

Other mechanisms utilizing NITINOL in different configurations are currently being designed and fabricated. Devices utilizing NITINOL can be competitively employed in many areas requiring relatively quick response and high driving force with severe limitations on the permanent magnetic field, weight and volume.

CONCLUSION

The mechanism described in this paper provides positive, cyclical indexing for a sensor rotating 180 degrees ±15 minutes; the permanent magnetic field is less than 0.1γ at 2.54 cm (one in), the power consumed is less than 240 watt-seconds, the weight is less than 0.168 kg (6 oz), and the volume (less the experiment container) is less than 3.6×10^5 cubic meters (2.25 cubic inches). Two mechanisms of the type described in this paper have been fabricated for feasibility testing. Eight additional units will be built, two of which it is contemplated will go aboard the 1977 Mariner Jupiter-Saturn spacecraft as the actuating mechanism for the low field triaxial fluxgate magnetometer experiment.

REFERENCE

1. Jackson, C. M., Wagner, H. J., and Wasilewski, R. J., "55-NITINOL — The Alloy with a Memory: Its Physical Metallurgy, Properties, and Applications." NASA-SP5110, 1972.

ADDENDUM

The actuator described in the Mechanical Operation Section of this paper (figure 4) has been modified as shown in figures 5 and 6. Refinement of the conceptual design necessary for the development of flight hardware has wrought most of the changes. However, one basic addition has been incorporated into the original concept; and that is the feature of a position lock.

This addition was necessitated because of the tendency of the NITINOL springs, after $>$ 1,000 flips and especially at low temperatures, to return to their strained shape upon cooling and therefore pull the crank arm off its position stop (figure 5).

The concept shown in figure 4 was modified to incorporate a mechanism which locks the crank arm in either its 0° or 180° position. As shown in figure 5 the outboard end of either NITINOL spring is reacted by a pivot arm which also carries two cam springs (tension), a follower and an arm stop. The two followers interface with a cam which has one slot. In figure 5 the left follower has engaged the cam slot and bears against the lower slot face thus eliminating play and locking the crank arm against its position stop.

When the NITINOL spring on the left is heated, its increased modulus reacts with the locked toggled spring crank on the right and the pivot arm on the left. As the force of the two cam springs is overcome the pivot arm and its slaved follower move counter clockwise, thus ultimately releasing the cam. The toggled spring crank is now free to be driven clockwise as in the previous concept (figure 4) and the crank arm rotates 180° to the left stop. The spring loaded right follower detents with the cam and locks the crank arm and its associated hardware in this position until it is again flipped back to the position as shown in figure 5.

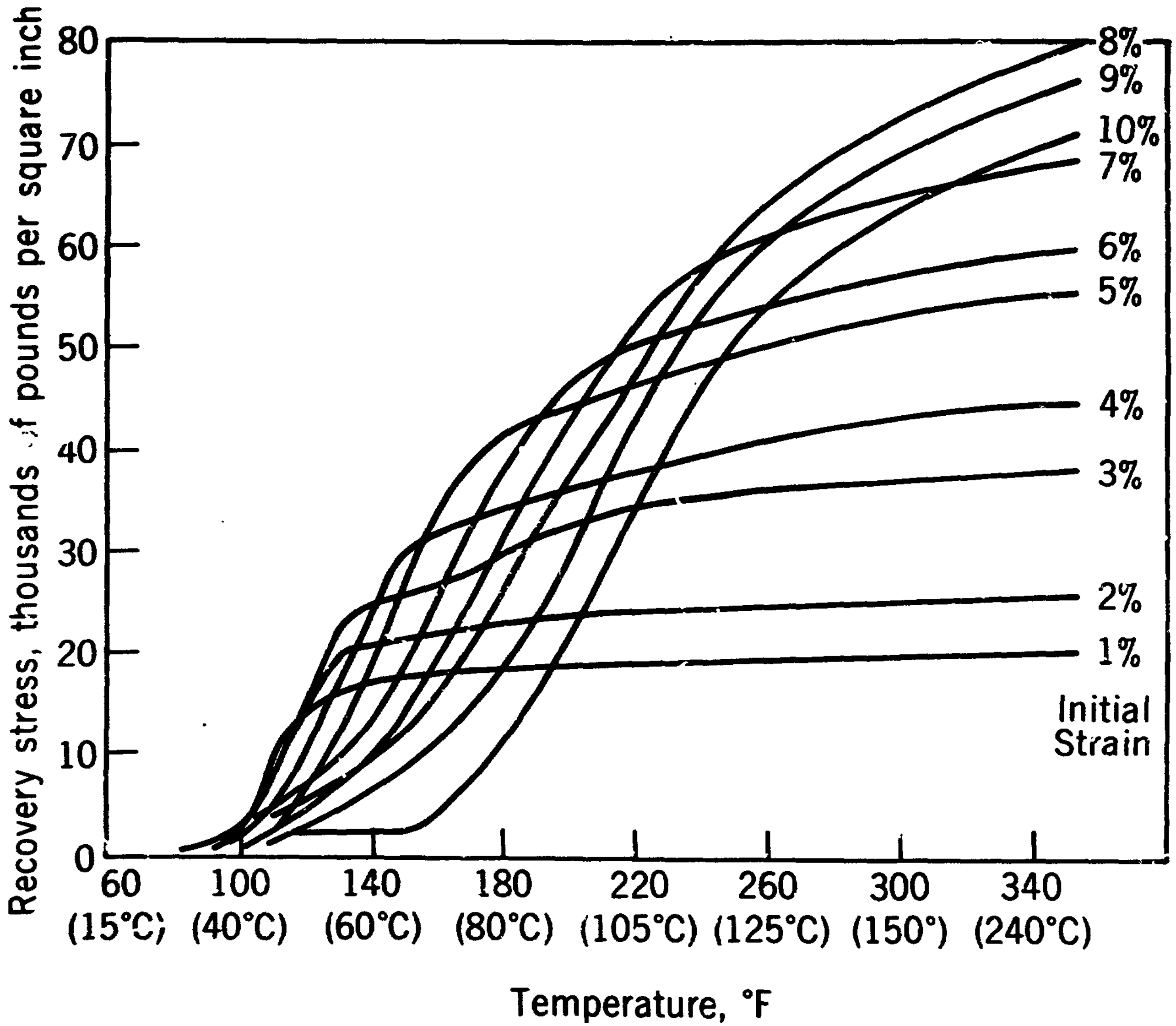

Figure 1. Typical Tensile-Recover-Stress Vs. Temperature Curves[1]

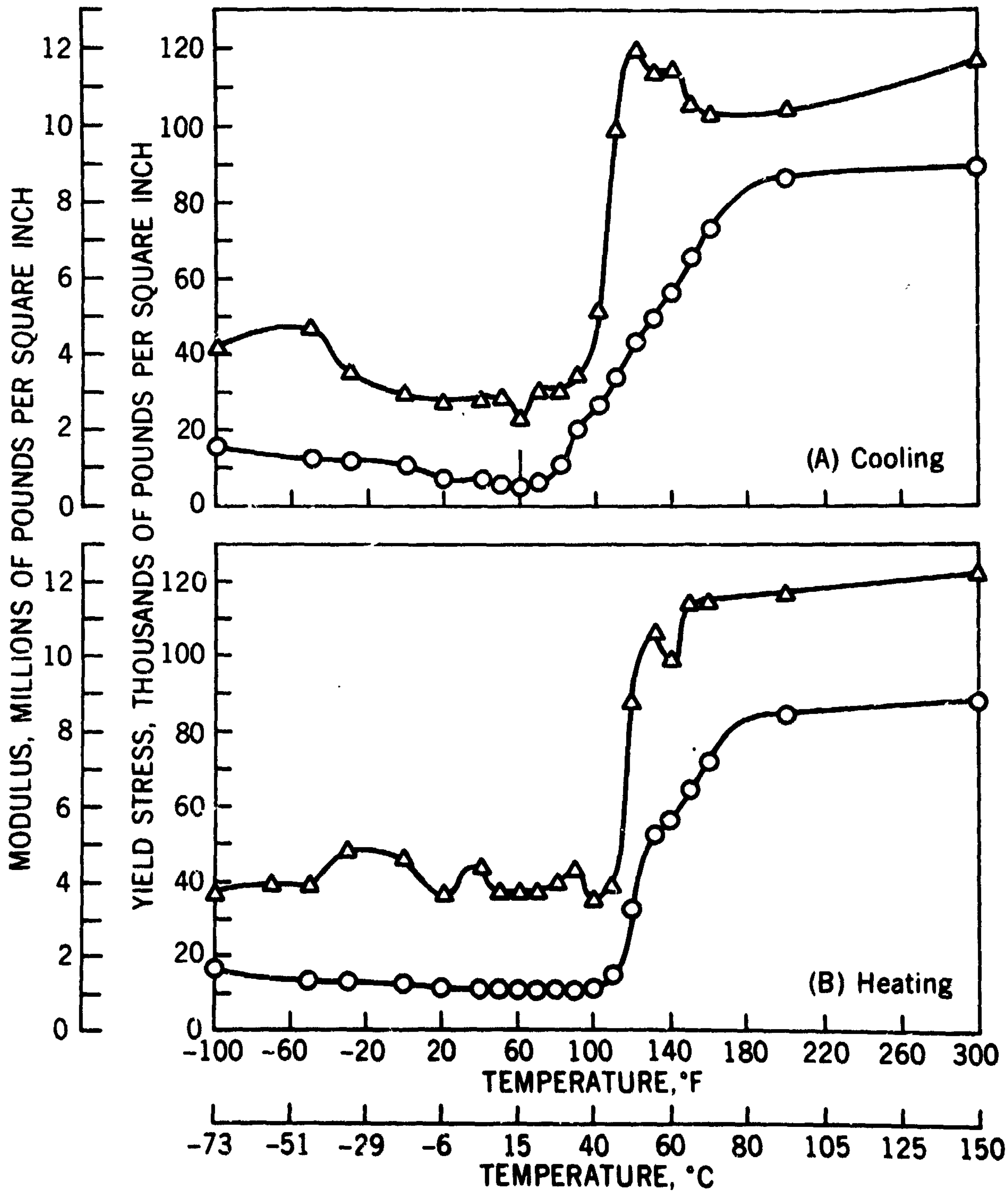

Figure 2. Typical Temperature Effect on Yield Stress and Modulus of Elasticity

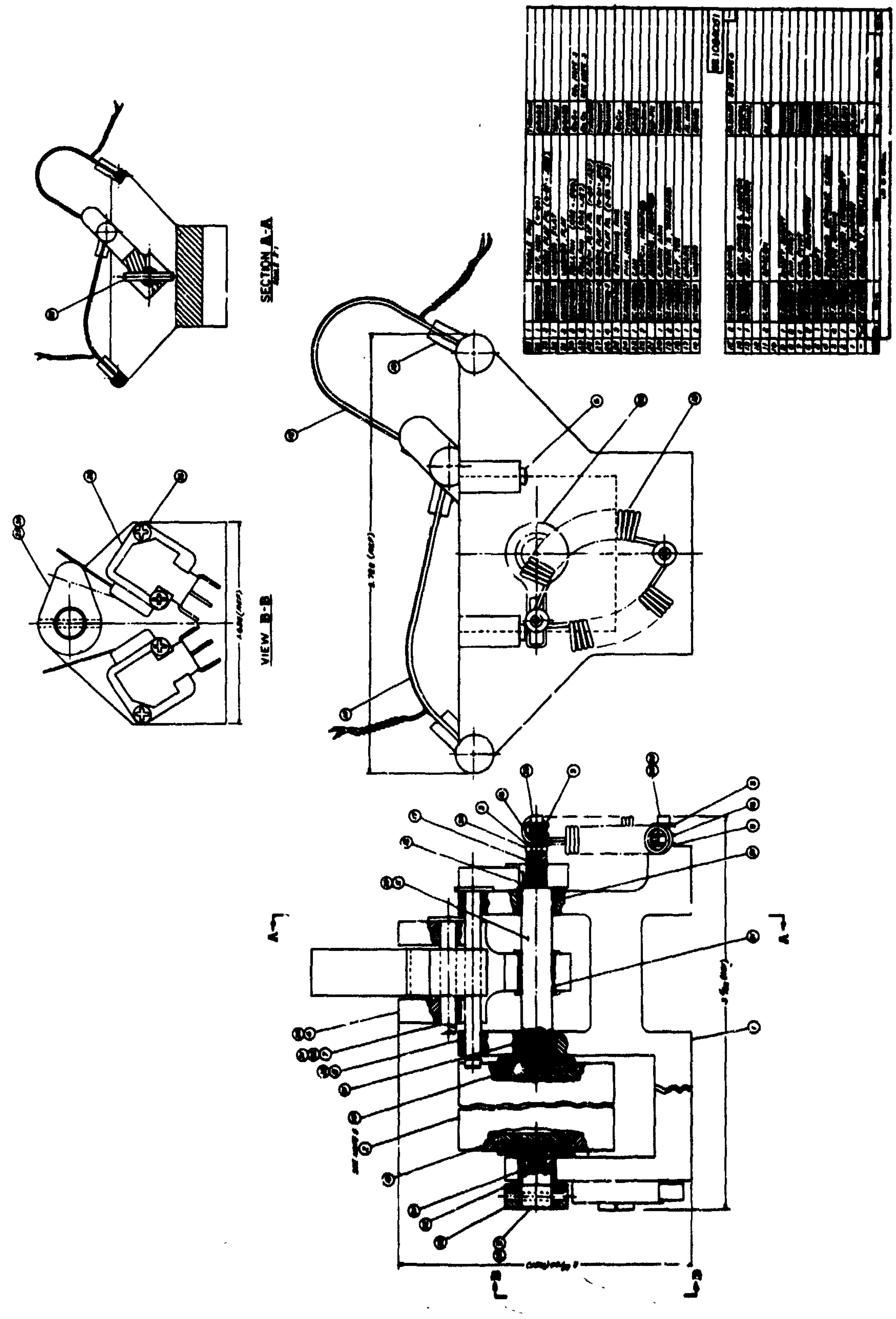

Figure 3. Assembly Drawing

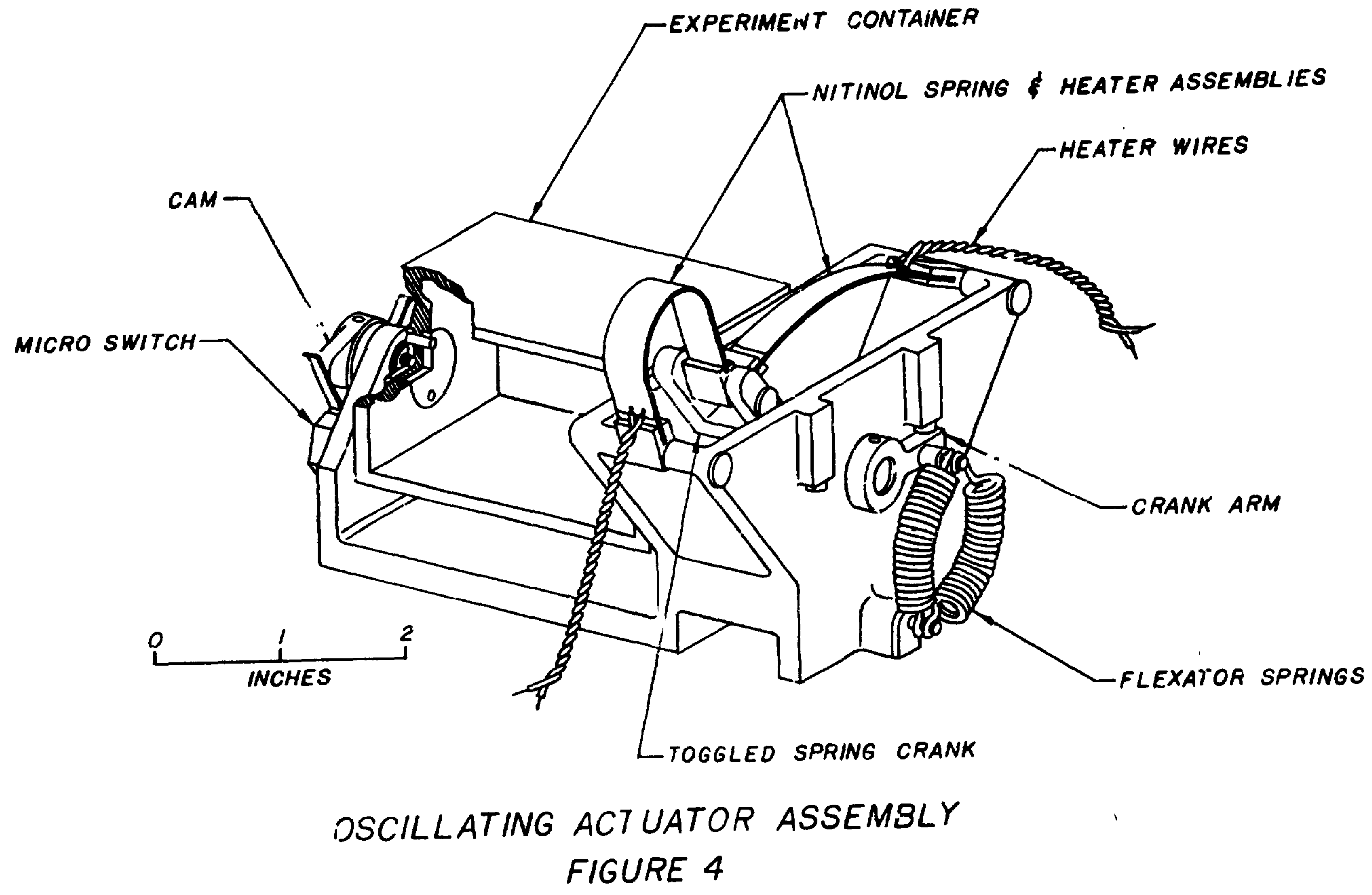

Figure 4. Oscillating Actuator Assembly

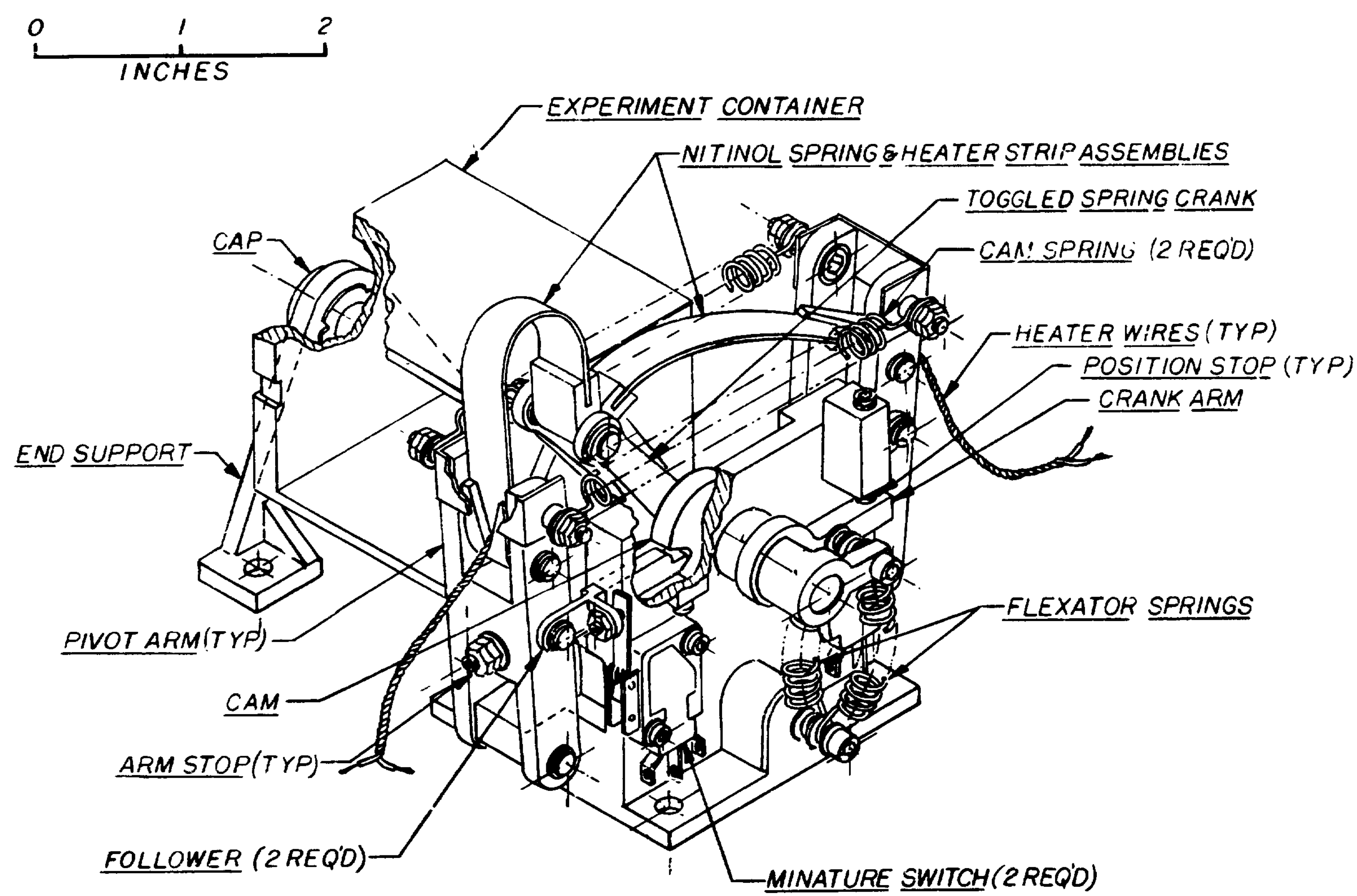

Figure 5. Oscillating Actuator Assembly

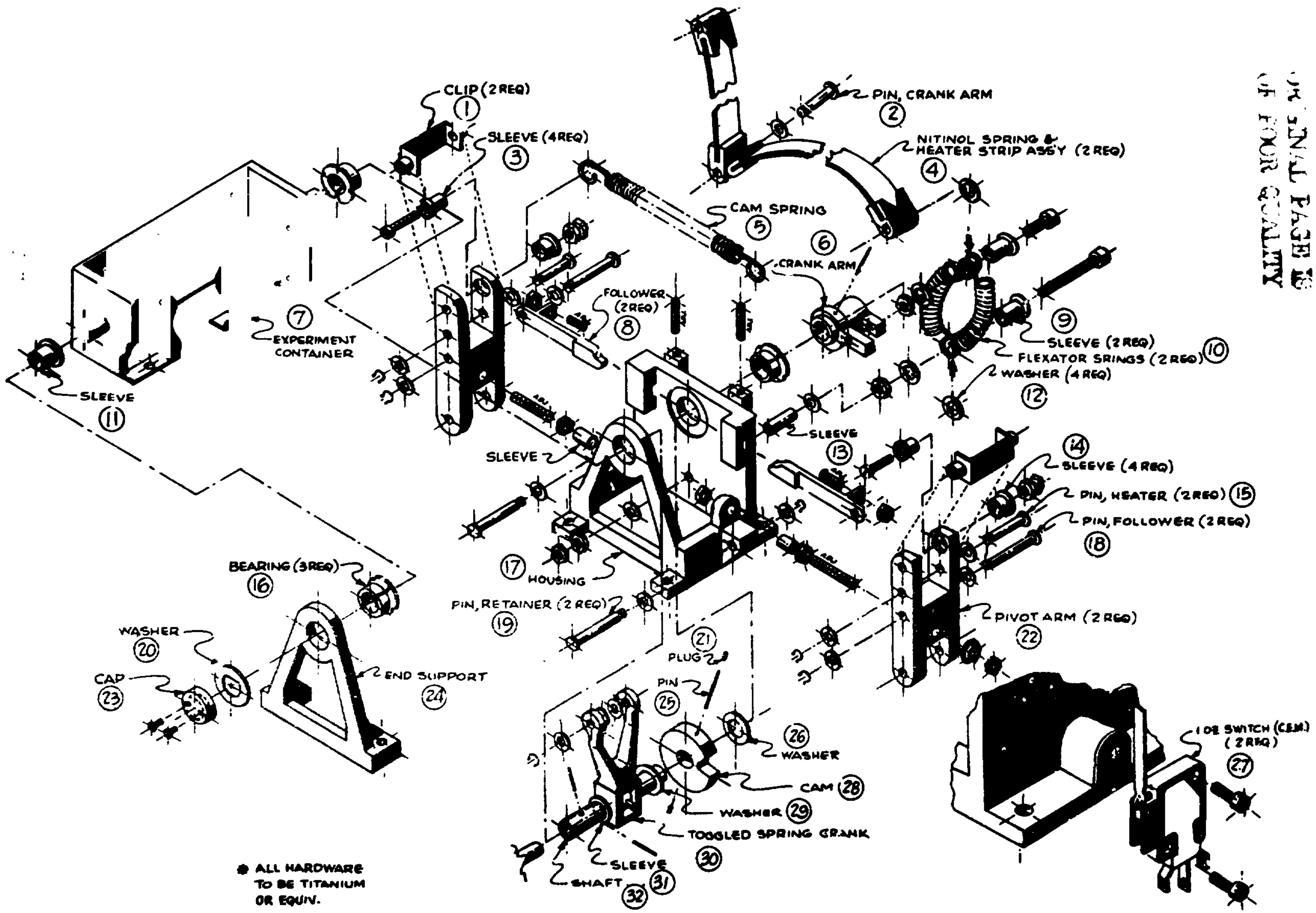

Figure 6. Exploded View–Oscillating Actuator Assembly