Nonmagnetic, Lightweight Oscillating Actuator

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The mechanism described provides a means of multiple indexing of a sensor to 90 deg ±15 min. The resulting permanent magnetic field, the power consumption, and the weight of the device are very low. The problems that were encountered in development and the results of the successful operation of the device in three spacecraft are presented.

I. Introduction

An essentially nonmagnetic indexing device was required for in-flight calibration of three orthogonal fluxgate sensors of the magnetometer experiment on *Explorers* 33, 34, and 35. The calibration, which determines the inherent drift in the sensors, is performed by periodically rotating the magnetometer sensors by 90 deg.

The magnetometer was designed to measure the interplanetary magnetic field in earth and lunar orbits. The intensity of the magnetic field in these regions is below 10γ; thus, it was essential to minimize the permanent field of the mechanism in order to measure the drift in the magnetometer.

The novelty of the mechanism resides in the use of a nonmagnetic thermal actuator to provide oscillatory motion operable under varying environmental temperatures (−35 to +70°C) in a vacuum for a long period with a high mechanical output-to-weight ratio for low power consumption. This paper describes the mechanical and electrical functions of the design which evolved, as well as the problems encountered. It concludes with an evaluation of the objectives achieved and suggests other applications for this device.

II. Objective

The objective was to develop a device which would

(1) Have a permanent magnetic field (when power was not being applied to the heater) less than 0.25γ at 3 in.

(2) Rotate 90 deg ±15 min of arc.

(3) Have a minimum capability of 500 cycles.

(4) Rotate the sensors within 10 min (the *on* time allocated for calibration of the sensors).

(5) Require less than 3.75 W (2,250 W-s) during actuation.

(6) Have a weight less than 0.5 lb.

(7) Fail-safe, i.e., the magnetometers must not stop in any position other than 0 or 90 deg.

(8) Operate within the temperature range of −35 to +65°C.

(9) Operate in a vacuum for at least 1 year.

III. Design

In selecting a design approach, other methods were considered: conventional indexing devices such as electrical stepping motors and solenoids were eliminated because of their inherent magnetic fields; a spring-powered, explosive-actuated, bistable escapement device is feasible but affords a limited number of actuations; and a bimetallic mechanism is entirely feasible and workable but it did not produce enough force to rotate three sensors as configured.

The oscillating mechanism employing a thermal actuator was adopted because the device could be made entirely of essentially nonmagnetic materials and it afforded a high ratio of mechanical output to electrical power at low weight and volume.

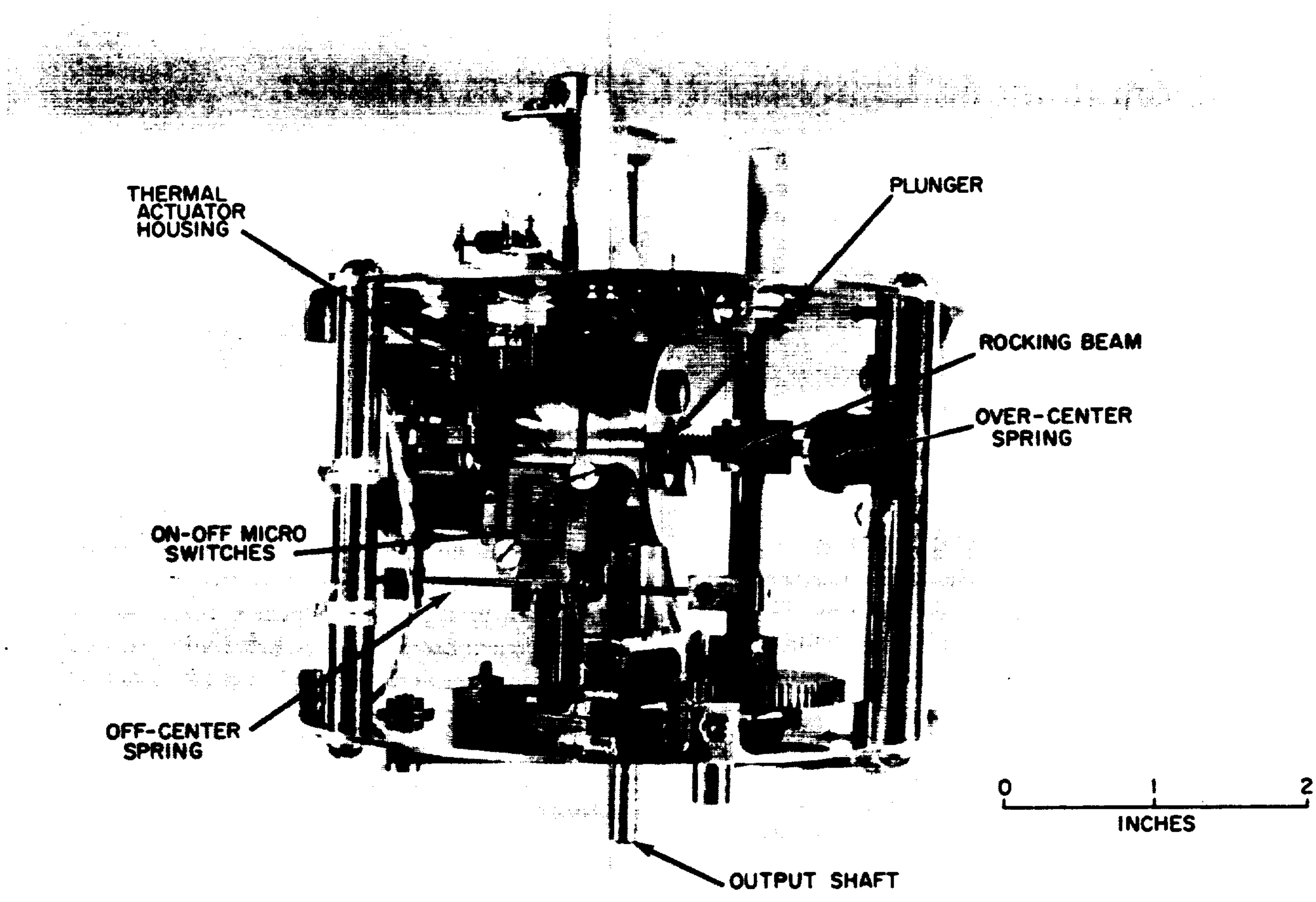

Fig. 1. Oscillating actuator assembly

IV. Mechanical Operation

The mechanism is shown in Fig. 1, and Fig. 2 is a sectional view showing the basic components. The mechanical operation is as follows: Electrical power is applied to a resistance heater plated on the thermal actuator (pellet), which is a paraffin-filled housing with a rubber boot and piston. The heater melts the solid paraffin, causing a volumetric increase of 10% which raises the internal pressure to 2,000 psi. This pressure on the rubber boot causes it to push on the conical tip of the piston, forcing it outward. The piston pushes against a rocking beam attached to a series of gears which rotates the sensors. The over-center spring provides a fail-safe operation, in that it allows the sensors to be only in either of the two desired positions when the electrical power is terminated, as shown in Fig. 3.

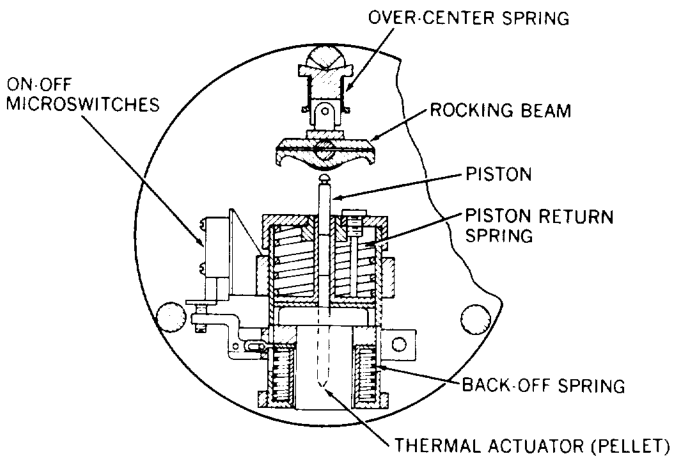

Fig. 2. Basic components of the actuator

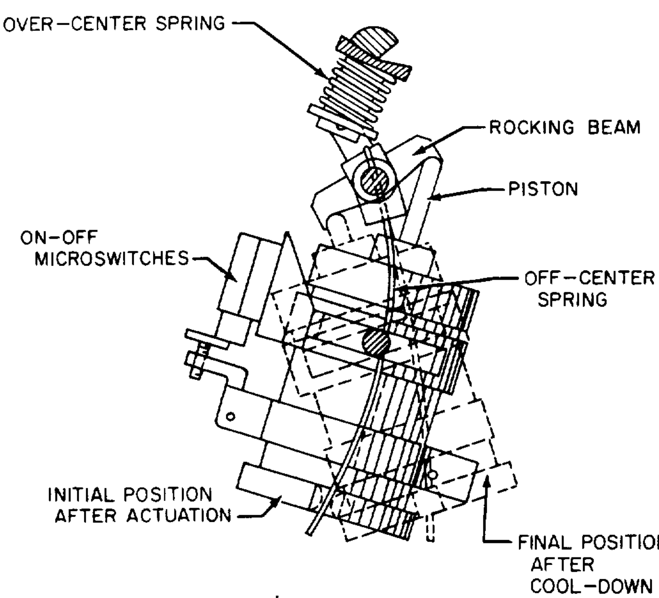

Fig. 3. Basic operation of the actuator

Once the mechanism has rotated the sensors within the allowable 10-min time duration, the remaining electrical power input and mechanical power output is dealt with by allowing the pellet to float between compression springs. After the piston has rotated the sensors, it continues to push with increasing force against the rocking beam until it overcomes the force of the back-off spring, whereupon the actuator moves away from the rocking beam and closes microswitches which turn off the power. This allows the pellet to cool and reduce its force until it moves back again, opening the microswitches and allowing heat to be reapplied. This cycling or floating action continues until the 10-min timer terminates the electrical power. This motion prevents any mechanical damage. If the sensors cannot rotate because of mechanical binding, the pellet is allowed to produce a maximum force before it is backed off.

At the end of the 10 min, a compression spring pushes the piston back into the pellet as it cools and the pressure decreases. An off-center spring, preloaded as the sensors rotated, swings the entire actuator over to the other side of the rocking beam to prepare for rotation in the opposite direction during the next cycle.

V. Wax Pellet Actuator

The wax pellet is a standard production line component[1] consisting of a copper case with a rubber boot, a paraffin material, and a piston. The material, which expands on melting, pressing the rubber boot against the conical tip of the piston and forcing it outward, is a mixture of Epolene and a paraffin wax, yielding the desired melting point. A fine copper powder is added to increase conductivity and provide for a more uniform temperature throughout the material. During the solid-to-liquid transition, a volumetric increase of 10% increases the internal pressure to 2,000 psi. Above the operating temperature of 71°C, allowance in piston overtravel must be 0.002 in. for each degree, because the internal pressure could reach 4,000 to 6,000 psi if overtravel were not allowed. The case is designed for 3,500 psi and will deform at higher pressures. After 500 cycles, the piston will

[1] Part No. 3005031 from the Harrison Radiator Division, General Motors Corporation.

index with a compression spring to within 0.010 in. of the original position, and the initial operating temperature will rise 1 to 3°C. The pellet weighs 26 g with approximately 750 mg of wax and has a maximum force of 35 lb (15,900 g) with a maximum stroke of 0.375 in.

VI. Materials

The prime considerations in the selection of materials for this device were low magnetic permeability and weight and adequate strength. All springs were made from Elgiloy, the bushings from Delrin, and the canister from fiber glass. The main structure was fabricated from aluminum, with critical wear surfaces hard-coated, to enhance the passive thermal design by polishing the surfaces. (Magnesium surfaces were not used because the need for plating them would have presented a handling problem.)

VII. Thermal Design

Passive thermal coatings controlled the temperature of the mechanism and sensors, which were encased by a fiber glass canister. The canister was coated on the inside with conductive silver paint to provide an RF shield and then scribed to reduce eddy currents. Thermal analysis indicated an interior and exterior coating of vapor-deposited aluminum with three circumferential stripes of white paint on the outside to maintain the sensor temperature between +10 and +50°C. Most of the components were highly polished aluminum in order to obtain a device which would contain most of the available heat by reducing emissivity. The pellet itself had a white paint outer layer to reduce its absorptance and was insulated with nylon bushings.

After the mechanism was optimized for power consumption, it was very sensitive to heat losses. As a result, it was important to isolate the mechanism from conduction and convection losses to ensure proper operation. Proper operating characteristics were obtained when the unit was tested in a vacuum environment.

VIII. Development Problems

The extreme magnetic cleanliness requirement demanded special consideration. Careful selection of materials and continual monitoring of fabricated pieces and procured items to determine that they had not been magnetically contaminated during manufacture were very successful. All the parts fabricated and finished at the Goddard Space Flight Center met the magnetic cleanliness requirement, as did all but two purchased items.

In one instance, the Elgiloy springs had oxidized during a heat treatment and the oxide coating was magnetic. The original microswitch cases were made of a glass-filled plastic resin that was found to be magnetic. Investigation revealed this to be a function of the fiber length. Lengthening the glass fibers corrected the condition.

Assembly of the mechanism was a very difficult problem. The mechanism appeared functional and accessible on the drawings but it became necessary to build assembly jigs in order to put the various components together.

The initial design utilized a bellows instead of the paraffin-filled pellet. A mathematical model of the mechanism, developed to determine the relationship of the various parameters in order to optimize the design for available power, identified the bellows working fluid combination that could provide the maximum force output for a given electrical power input. The results indicated that an isoamyl alcohol working in a beryllium copper bellows yielded the optimum design for this specific application. However, utilization of the bellows presented several problems:

(1) Centrifugal force and the fact that the bellows could not be oriented to bring the alcohol in intimate contact with the heater required more power to conduct heat along the bellows to the fluid.

(2) Since the thermodynamic characteristics of the bellows were a function of the vapor mixture contained in the bellows, it was required that the bellows be filled with only isoamyl alcohol liquid or vapor and sealed at a pressure less than atmospheric at room temperature – a difficult but attainable filling procedure.

The thermal actuator was very attractive for this design because of its high ratio of power output to weight; however, its adoption was strongly dependent upon the ability to provide a reliable nonmagnetic heater in intimate contact with the case. A method was developed for vapor-depositing a gold heater directly to the case in a pattern that minimized magnetic fields. Its measured magnetic field in the operating condition was less than 1γ at 2 in. The heater was 9⅜ in. long and 460 Å (1.84 μin.) thick, thus providing a resistance from one heater to another of 80 ± 5 ohms.

IX. Alternative Uses

This mechanism is currently planned for many more satellites which require in-flight calibration of fluxgate-magnetometer sensors. The device can also be employed to actuate shutters or covers or to operate in remote areas where solar heat could be used as the heat input to operate the mechanism.

The metal bellows could be employed instead of the paraffin-filled element if it were not feasible to expose the rubber boot to an environment. Also, different gear combinations allow variable angular oscillatory motion.

X. Conclusion

The mechanism described in this paper provides positive, repetitive indexing, with the sensor rotating 90 deg ± 15 min, the permanent magnetic field less than the required 0.25γ, the power consumed less than 4 W, and the weight less than 0.5 lb.

Three mechanisms have been utilized on spacecraft, with the one employed on *Explorer* 33 having the longest duration in the space environment. As of May 1968, this mechanism has operated once per day for 670 consecutive days where temperatures have ranged from +50 to −120°C (during a long earth shadow). All three mechanisms continue to operate with no sign of degradation.

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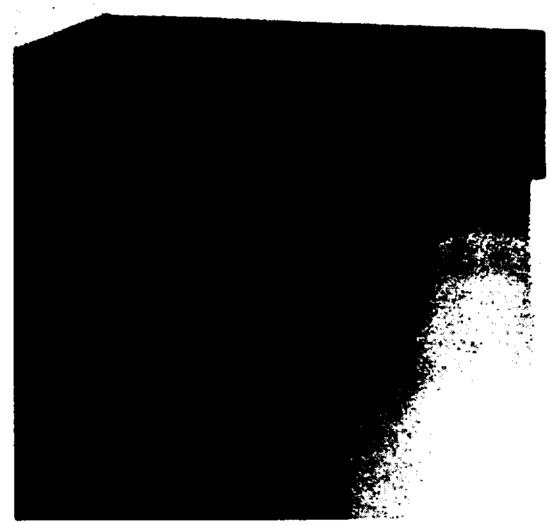

Session IV

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