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CAGING MECHANISM FOR A DRAG-FREE SATELLITE POSITION SENSOR

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ABSTRACT

A disturbance compensation system for satellites based on the drag-free concept has been mechanized and flown, using a spherical proof mass and a cam-guided caging mechanism. The caging mechanism controls the location of the proof mass for testing and constrains it during launch. Design requirements, design details, and hardware are described.

INTRODUCTION

A navigation satellite launched by the Applied Physics Laboratory of Johns Hopkins University incorporated a device built at Stanford University for the compensation of external forces, e.g., atmospheric drag and solar radiation pressure, which perturb a satellite's orbit.

If we enclose an object (proof mass) in a housing which isolates it from the drag and solar radiation pressure, it will follow an orbit influenced solely by the gravitational field of the earth. If the satellite is constrained to follow the proof mass, it will follow a similar gravitational orbit. Such an orbit can be predicted for much longer times than the orbit for a satellite calculated on the best estimates of drag and solar disturbance [Refs. 1 and 2].

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The accuracy of navigation on the earth's surface by ships or aircraft, and the extension of measurement resolution in the fields of aeronomy and geodesy are all areas which can benefit from the long-term predictable orbits made possible by DISCOS (Disturbance Compensation System).

The DISCOS consists of a spherical proof mass within a housing, a capacitive sensing system to detect proof mass position, a propulsion system to position the satellite relative to the proof mass, a caging mechanism to control the location of the proof mass for testing and launch, and the electronics necessary for operating the control system and providing telemetry information and receiving commands.

The satellite for which the DISCOS was designed was a three-body gravity-gradient three axis stabilized configuration with an overall length on orbit of 7.5 m (Fig. 1). The DISCOS was contained in the center body, a 300 mm diameter by 300 mm long cylinder attached to the other two bodies by folding booms.

DISCOS DESCRIPTION

The DISCOS is made up of five major components: the proof mass, proof mass housing, electronics, propulsion subsystem, and the caging mechanism (Fig. 2). These components are arranged in the cylindrical housing in a manner which tends to minimize the mass attraction force of the components on the proof mass; that is, the parts are kept as far away as possible and as symmetrical as possible. Our familiarity with mass attraction is, in general, limited to the earth's, i.e., the weight of objects around us. In the design of a drag-free satellite, however, the disturbance forces to which the proof mass is subjected must be kept smaller than the order of 10^{-11} g, which, for comparison, is the attractive force exerted on the proof mass by a 15 gm mass at a distance of 100 mm. For this reason, the size and location of all parts of the DISCOS had to be controlled and known to dimensions as small as 0.01 mm.

The most important and at the same time the simplest component of the system is the proof mass—a sphere 22 mm in diameter, mass of 0.11 kg, cast from a 70 – 30 gold-platinum alloy and lapped to size. The proof mass is contained in a beryllium oxide housing of 40 mm inside diameter. The caging mechanism penetrates the wall of this housing to provide control of the proof mass. The inside surface of the proof mass housing is coated with vacuum deposited chromium in a pattern of three orthogonal pairs of capacitor plates. The change in capacitance caused by motion of the housing relative to the proof mass is sensed to obtain satellite position data. The other major items of the DISCOS are the electronics and propulsion subsystems.

MECHANISM DESCRIPTION

The caging mechanism for the DISCOS performs two functions. First, it is used to move the proof mass in a prescribed path inside the housing so that the signals from the three pairs of capacitive plates can be checked. To a degree, this is a simulation of the normal orbit condition where the proof mass would be free to sense the motion of the satellite.

The caging mechanism serves the second purpose of securing the proof mass against motion during launch and ascent to orbit. To meet this caged position requirement, the mechanism was designed to exert a force of 54N when securing the proof mass.

The caging mechanism (Fig. 3) is located below the proof mass housing, and the caging rod, a beryllium oxide cylinder 12.7 mm diameter by 46 mm long with a mass of 0.017 kg, extends upward into the housing. The lower end of the caging rod is pinned to two circular springs, which are in turn pinned to a transfer nut. The springs are fabricated from beryllium copper and the transfer nut is 303 stainless steel. The transfer nut travels on a 1/4"-16 Acme screw, also fabricated from beryllium copper. The lower end of the caging rod follows a two-dimensional cam slot cut into two plates on the side of the mechanism, thereby imparting the desired motion to the proof mass for systems tests. The cam slot is designed to move the proof mass along a path resembling a sinusoid. The beryllium oxide caging rod is furnace brazed to a clevis end fitting of 17-4 PH stainless steel. Initially, a titanium end fitting was tried but there were excessive voids in the joint due to insufficient wetting. The procedure which finally was used was to sputter approximately 4000Å of gold on the rod end, 10 µm of gold on the end fitting, and vacuum braze at 850°C with a gold-copper alloy (Englehard 378). The brazing temperature was held as low as possible to prevent grain growth in the beryllium oxide rod. In spite of this there was an increase in the rod diameter requiring an additional lapping operation to resize.

The acme screw is driven by a size 9 permanent magnet d-c motor geared to produce 23 mm travel of the transfer nut in 30 sec. The motor bearings are Barden ball bearings with a self-lubricating composite retainer, and the gear box is lubricated with Microseal 100-1. The motor was being produced for a program which had a similar launch environment and was purchased off-the-shelf. A modified Oldham's coupling is used between the motor and the screw.

The frame on which the components of the mechanism are mounted was machined from a piece of 6061-T6 aluminum 62.5 mm diameter by 100 mm long. The surfaces contacted by the transfer nut were given a hard anodize to minimize wear. An assembly fixture was fabricated for use in obtaining alignment of the two cam plates with respect to each other, for checking the switch trip points, and for measuring the spring load.

During operation in the caging direction, the first 0.86 mm travel of the transfer nut relieves the spring load which has been applied by stretching the springs during the uncaging cycle. Free travel then takes place for 21.25 mm during which the cam slot is traversed. At the end of free travel, the proof mass contacts the proof mass housing and the two springs are compressed a distance of 1.17 mm. This produces the load of 54N giving a longitudinal acceleration capability of 43 g without motion of the proof mass away from its caged position. At the end of spring compression, a tab on the transfer nut contacts a limit switch and power is removed from the motor. A pair of switches arranged to operate independently is used at each end of the stroke. Thus, opening either switch of the pair will remove power from the motor. Should both switches fail to open, the transfer nut will contact a steel pin after an additional 0.25 mm travel and stall the mechanism. This is done to prevent cracking or spalling failures of the beryllium oxide housing and caging rod.

TESTING

The systems check-out and testing phase for the DISCOS required a number of caging and uncaging cycles for the determination of electronic signal strength and scale factors for the position sensing system. Tests were performed at ambient conditions, in vacuum at 45°C and -20°C both before and after vibration testing. Several hundred caging and uncaging cycles were performed during the test period.

CONCLUDING REMARKS

One caging mechanism was fabricated to serve for both system qualification and the flight vehicle. At the completion of testing, the cycle time on the unit was within 1 sec of the desired time. Following launch and orbit injection, the mechanism remained in the caged position for eleven days, at which time it was uncaged by ground command.

ACKNOWLEDGMENTS

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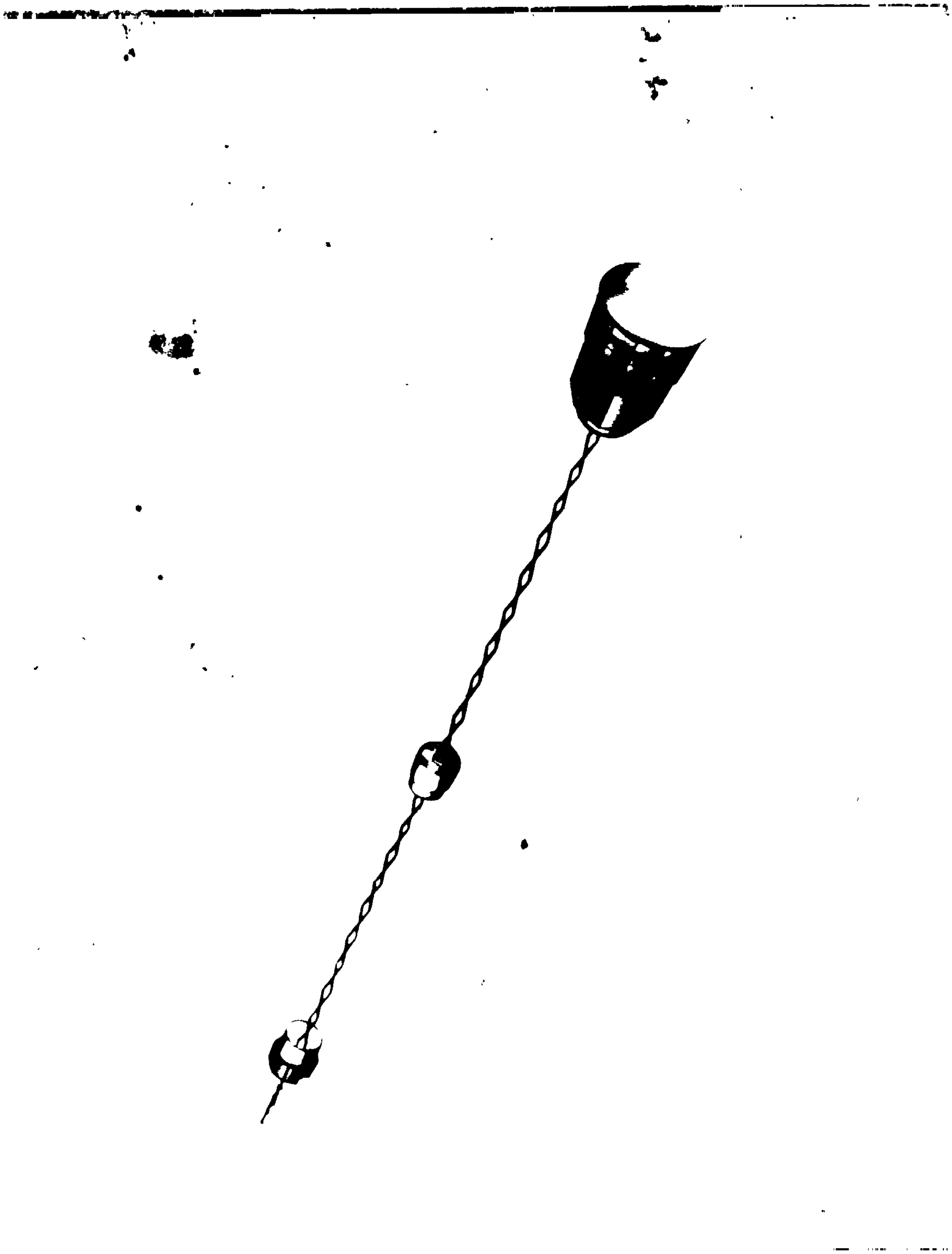

FIG. 1 NAVIGATION SATELLITE WITH DISCOS HOUSING IN CENTER.

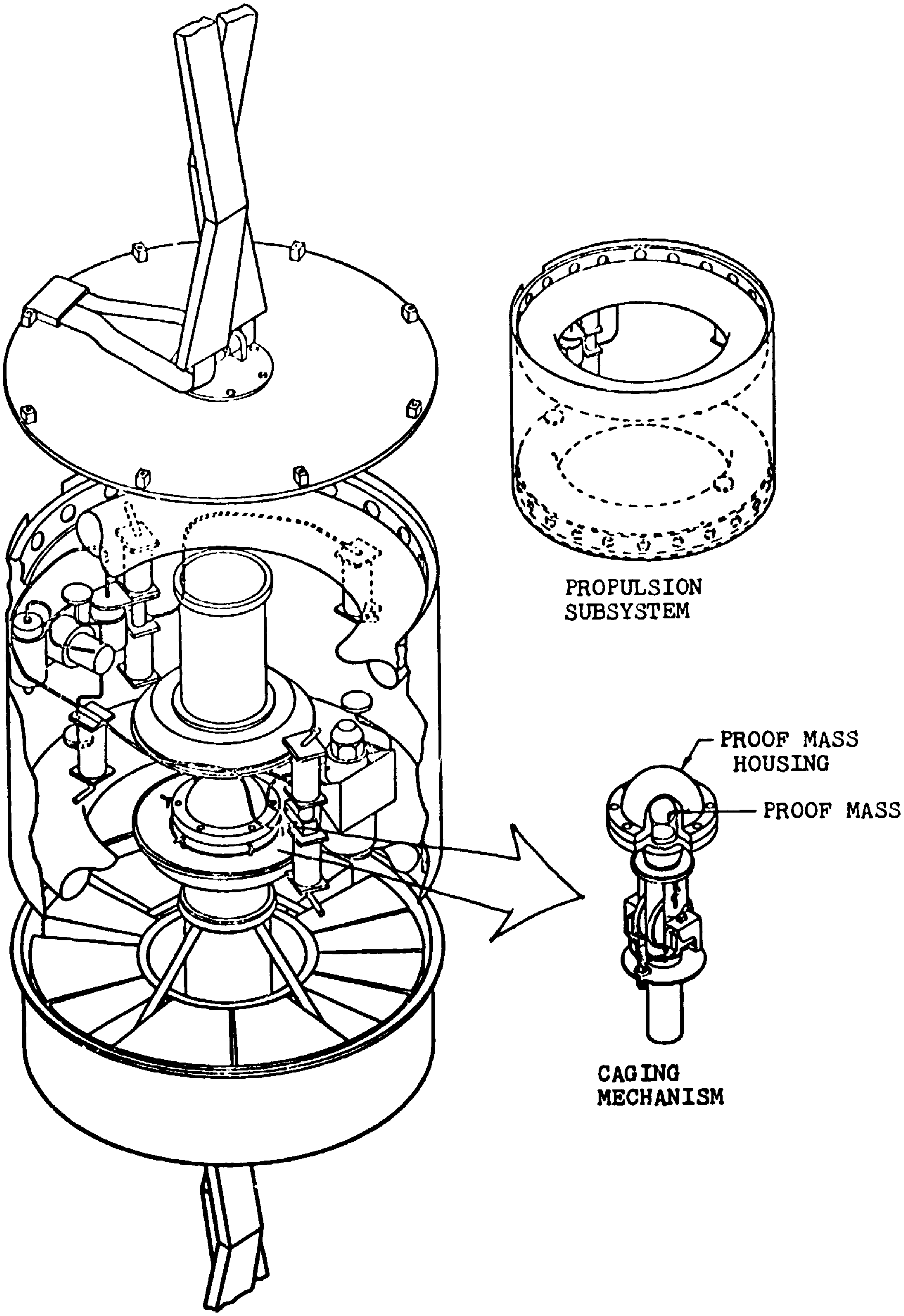

FIGURE 2 DISCOS SHOWING LOCATION OF CAGING MECHANISM.

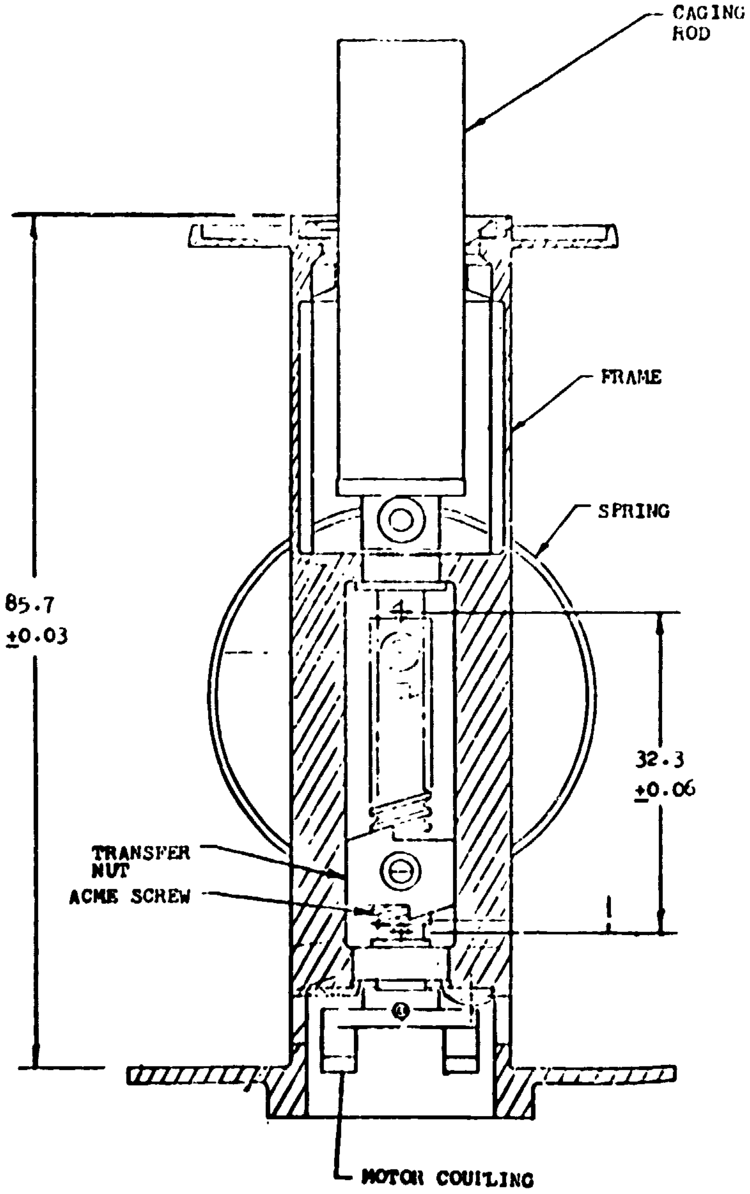

FIGURE 3 CROSS SECTION OF CAGING MECHANISM.