A Torsion Wire Damping System for the DODGE Satellite*

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The torsion wire damper developed for the Department of Defense Gravity Experiment satellite is described. The damper, which was designed by the Applied Physics Laboratory of The Johns Hopkins University, incorporates two separate damping devices: an eddy current damper and a hysteresis damper. The torsion wire suspension system and caging mechanisms used are described in detail. The damper has operated in space since July 1, 1967.

I. Introduction

The *Department of Defense Gravity Experiment* satellite (DODGE) was launched on July 1, 1967. The primary objective of the satellite was to demonstrate that gravity-gradient stabilization is achievable at near-synchronous altitudes. It was designed to investigate 2- and 3-axis gravity-gradient stabilization using a variety of libration damping techniques in determining correlation between theory and experiment. The torsion wire damper is a component of one of these systems.

The torsion wire damper provides a suspension system of variable moment of inertia, coupled to the spacecraft body by a weak spring. The natural frequency of this system is such that maximum coupling between modes is achieved. Two separate experimental passive magnetic devices are used to dissipate the energy of the system. The dampers are adjustable in space, upon command from earth.

References 1, 2, and 3 describe theoretical analyses of torsion wire damping systems. Reference 4 analyzes gravity-gradient stabilization at synchronous altitudes and Ref. 5 describes the DODGE satellite. The overall design and performance of the torsion wire damper are described in this paper.

II. Design

A. General

The torsion wire damper is mounted in a mast that protrudes from the main body of the DODGE satellite (Fig. 1). The damper consists of the torsion wire suspension system with two extendible boom mechanisms (with

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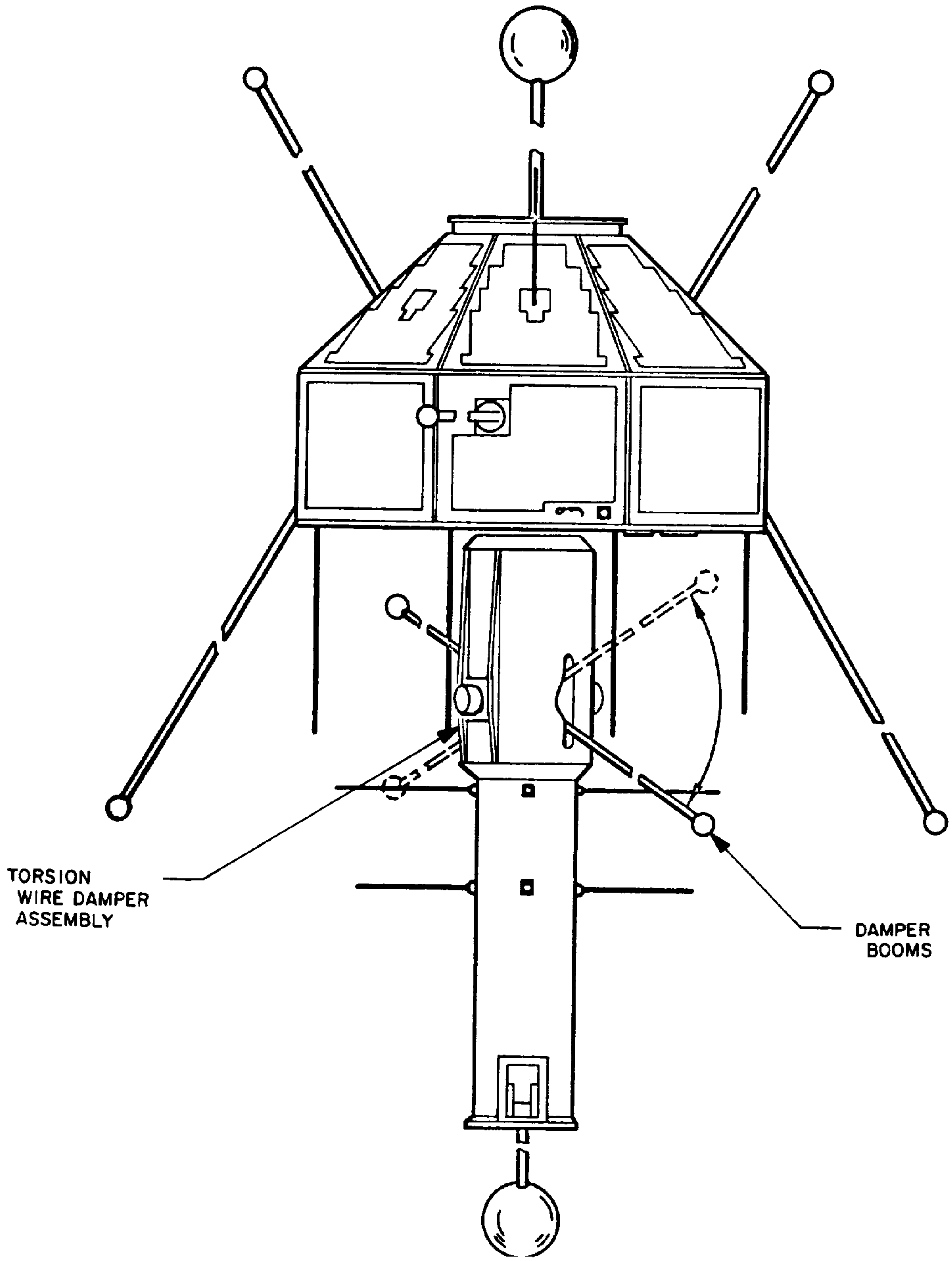

Fig. 1. The DODGE satellite, showing the damper assembly and booms

end masses attached), each of which is mounted at 180 deg with respect to the other and extends through slots cut in the mast. The delicate (0.003-in.-diameter) torsion wire provides an essentially frictionless suspension as well as a restoring torque that causes the damper booms to seek a rest position when the satellite is at rest under gravity-gradient stabilization. The spring constant of the wire is 85 dyn-cm/rad.

The boom mechanisms on DODGE are DeHavilland Model 5489F1-11 Motorized STEM units, with ½-in.-diameter, 2-mil-thick beryllium copper boom tape, silver plated on the outer surface with a reflectivity of about 0.90. A boom mechanism with end mass in the launch position is shown in Fig. 2. Maximum extension capability of the damper booms is 50 ft. Other booms on DODGE have a maximum length of 150 ft.

B. Torsion Wire Suspension System

The torsion wire suspension system consists of two extendible booms suspended between two fine wires

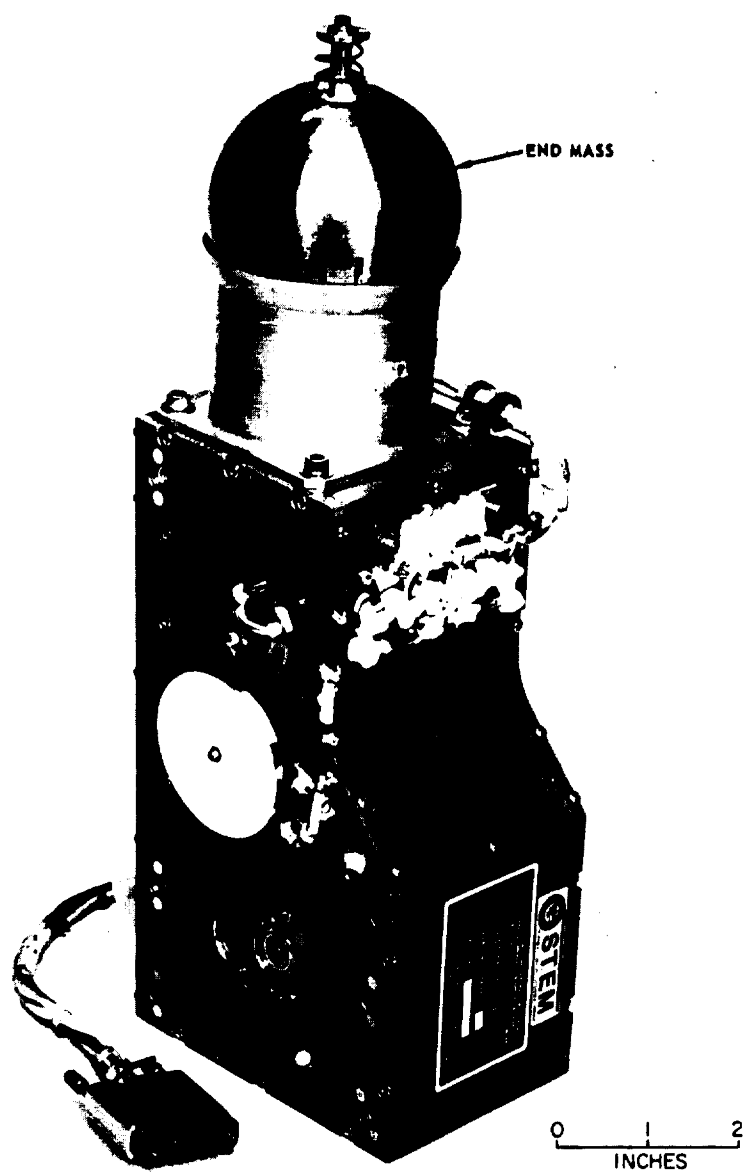

Fig. 2. Boom mechanism with end mass

which act as a torsion spring. The boom mechanisms are mounted side by side in a single housing so that the booms deploy in opposite directions. The entire damper system, including the suspension system, is shown in Fig. 3.

The torsion wires are steel music wire, 0.003 in. in diameter. The ends of the wire are held in tapered chuck grips machined from soft brass. Considerable care was given to the design of the grips to minimize stress concentrations which could result in fatigue failure of the wire during launch. These grips react all of the bending moment and all of the torsion load from the wire and most of the tensile load. The wires are secured to the rear of the grip with solder and are attached to the spacecraft body through soft leaf springs which allow a small axial movement of the damper assembly without damage to the wire. Limit stops are provided so that the damper assembly will strike a stop when moved in translation 1/16 in. in any direction from its center position. By the use of two nuts which lock the grip on the leaf spring, a wire tension of about ½ lb was obtained.

The rest position of each wire was determined by aligning each end in a special fixture as the wire hung free. The grips were marked so that this alignment could be maintained when the wires were installed in the damper assembly.

C. Caging Mechanisms

There are two separate caging mechanisms. The first, which provides protection to the entire torsion wire damper during the launch environment, is called the launch lock. The second, called the orbit lock, was designed to prevent oscillation of the torsion wire system

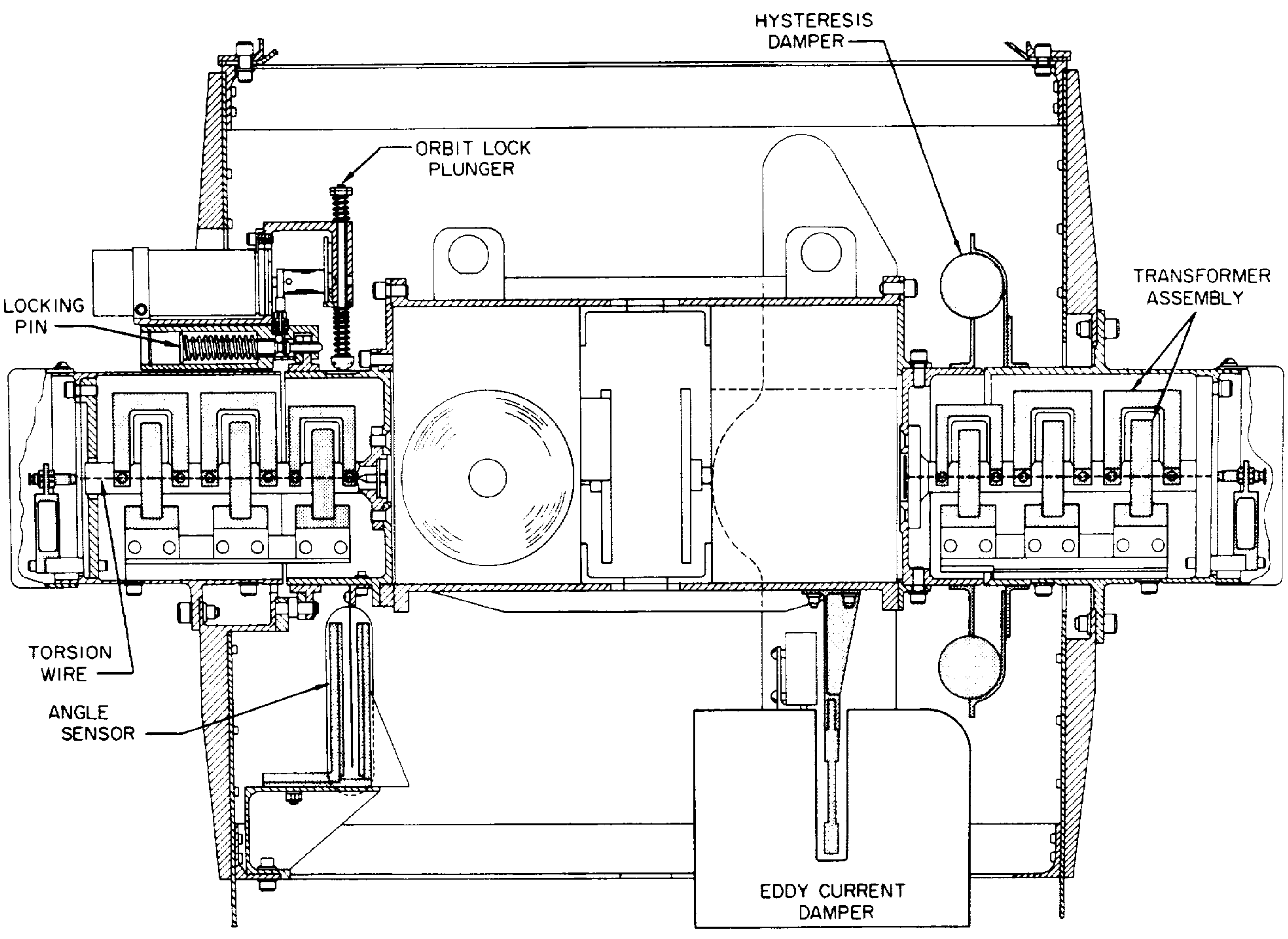

Fig. 3. Drawing of the torsion wire damper assembly

in orbit on command. Both locking systems are operated from a common shaft driven by a hysteresis synchronous motor with a gearhead whose output shaft turns at 1 rpm.

The launch lock operates from one end of the suspension system. The other end is captured by moving the suspension system off center and seating it in a tapered seat. The launch lock itself consists of two semicircular clamp halves hinged at one end (Fig. 4). These clamp halves secure a cylinder which is an integral part of the damper boom housing. In the locked position, the clamp halves are closed and held with a pin. Two flats on the clamp halves and the cylinder prevent rotation of the system, and two cleats mounted on the cylinder bear upon the clamp halves when locked to prevent the assembly from backing away from the tapered seat.

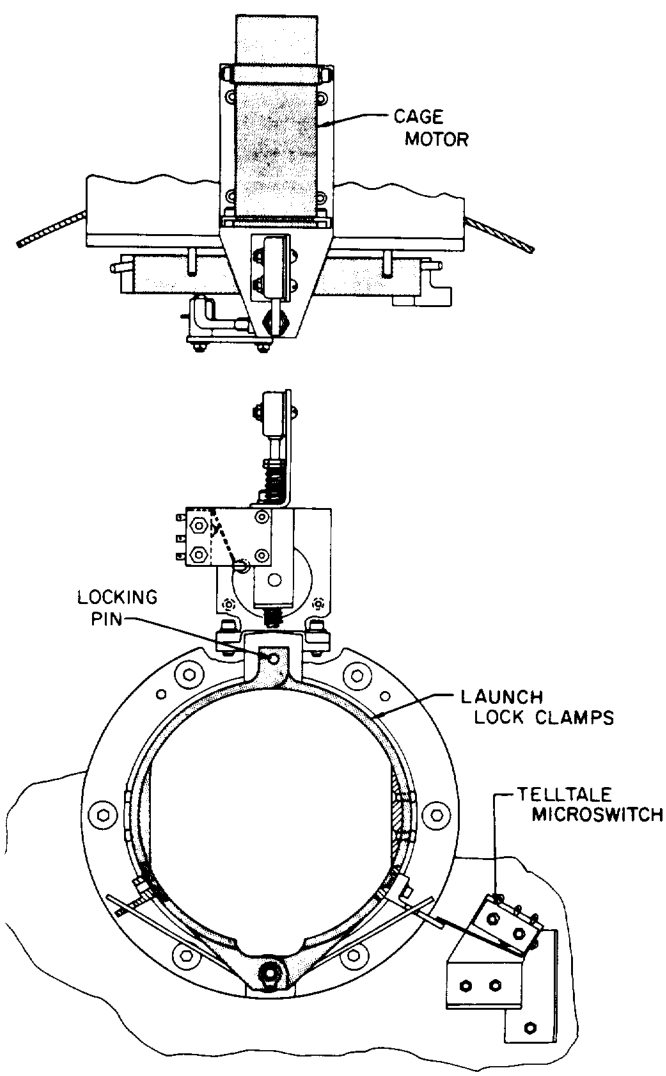

Fig. 4. Launch lock clamping system

The release mechanism is essentially a spring-powered pin puller (Fig. 3). When the pin is in place, i.e., holding the clamp halves in the clamped position, the spring is fully compressed and held in place by a check ball which in turn is restrained by a cam. When the cage motor is started, the cam rotates, releasing the ball, which is then forced out of its seat by the spring. The release mechanism is thus triggered and the spring withdraws the pin. Another spring on the clamp halves forces them apart once the pin is removed and the unlocked condition is achieved.

The launch lock was designed as a single-function device. The lock is set manually before launch or test. Once released, it serves no further function and can only be reset manually.

The orbit lock consists of a plunger which, upon actuation, applies a lateral load to the torsion damper assembly, pushing it against the limit stop. The plunger is actuated toward the lock position with a cam. A return spring allows the plunger to follow the cam away from the lock position. The cam is mounted to the output shaft of the same motor gearhead combination described above. The head of the orbit lock has a hemispherical tip which is designed to seat in a hole in the torsion damper assembly. The seat enables the lock to cage the damper at an angle of 0 deg. The seat is tapered so that the lock will cage at 0 deg from a position of ± 3 deg. The cam actuates the plunger through a spring which is designed to prevent jamming, to allow the cam to complete its rotation, and to permit the lock to operate whether or not the plunger is in the zero-position hole. The orbit lock can be used repeatedly.

D. Electrical System

All the motors on the DODGE spacecraft are hysteresis synchronous motors with appropriate gearheads to preclude the necessity of commutator brushes or hermetic sealing. The motor and gearhead bearings use dry lubricant for long life in the space environment. The power source is 31-V, 400-Hz square wave, and all boom mechanisms and the caging mechanism are powered in this manner.

Electrical connections to the damper booms had to be made in such a manner that no friction would be introduced to the suspension system. This was accomplished by transformer coupling (Fig. 3). The primary winding and core of the transformers are mounted rigidly to the satellite structure, whereas the secondary winding is mounted on the suspension system and rotates with it. There is no mechanical contact between the primary and secondary. There is an additional transformer for the telemetry signal which monitors boom length. Using this system, the booms may be operated with the suspension system at any angle, and with the suspension system locked or unlocked.

E. Angle Sensor

The suspension system is provided with an angle-sensing device which continuously reads the angle of the suspension system relative to the spacecraft axes. A thin fan-shaped member is attached to the suspension system. Slots etched in the fan form a binary gray code. The sensor, which is rigidly attached to the spacecraft, is a digital device made up of a row of six photo-emitters with photo-transistors as detectors. The detectors sense light which passes through the slots in the moving fan. The output of each detector provides angular position data with a resolution of 1.2 deg.

III. Damping Systems

The torsion wire damper assembly incorporates two separate damping devices: an eddy-current damper and a hysteresis damper.

A. Eddy-Current Damper

The eddy-current damper consists of a copper vane that moves through the field of a chargeable horseshoe magnet. While the satellite is in orbit, this magnet can be magnetized between zero and full magnetization by discharging a condenser through an electrical winding about the magnet. A Hall-effect detector determines the flux level of the field and is calibrated as an indicator of damping constant. By varying the level of magnetization, the damping constant can be varied from zero to the limit of the system.

B. Hysteresis Damper

A second damper in the assembly uses magnetic hysteresis as a means of damping. An electric coil surrounding a strip of high-hysteresis-loss magnetic material creates, by command from earth, different magnetic field levels, including zero. The energy of motion of the damper is dissipated by hysteresis loss in the magnetic material.

IV. Flight Experience

The torsion wire damper assembly is shown in Fig. 5. The launch caging system performed its function, which was to protect the damper during launch, and upon command was successfully released. The booms have been used many times and, as of this writing, all portions of the torsion wire system are operating as designed. The one aspect of the damper that did not function as designed was the torsion wire alignment. The rest position of the suspension system is not zero but is biased toward one side. All the causes of this bias are not known, but mechanical misalignment may be a contributing factor. On future spacecraft using this system, a more precise method of alignment will be employed.

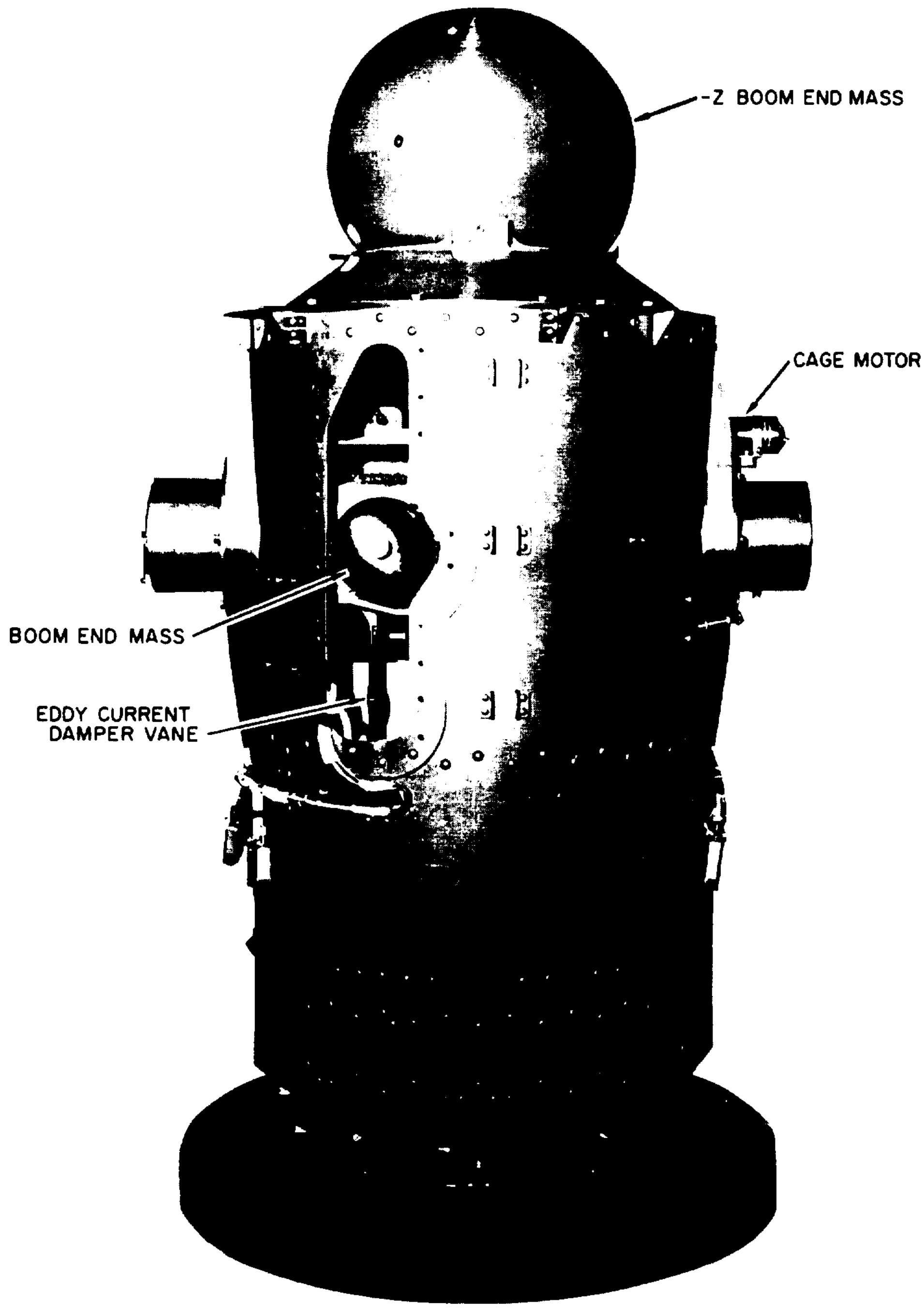

Fig. 5. Photograph of the torsion wire damper assembly

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