N91-24606

"DEAD-BLOW" HAMMER DESIGN APPLIED TO A CALIBRATION TARGET MECHANISM TO DAMPEN EXCESSIVE REBOUND

Brian Y. Lim*

ABSTRACT

An existing rotary electromagnetic driver was specified to be used to deploy and restow a Blackbody Calibration Target inside of a spacecraft infrared science instrument. However, this target was much more massive than any other previously "inherited" design applications. The target experienced unacceptable bounce when reaching its stops. Without any design modification, the momentum generated by the driver caused the target to bounce back to its starting position. Initially, elastomeric dampers were used between the driver and the target. However, this design could not prevent the bounce, and it compromised the positional accuracy of the calibration target. A design that successfully met all the requirements incorporated a sealed pocket 85 percent full of 0.76-mm diameter stainless steel balls in the back of the target to provide the effect of a "dead-blow" hammer. The energy dissipation resulting from the collision of balls in the pocket successfully dampened the excess momentum generated during the target deployment. This paper describes the disastrous effects of new requirements on a design with a successful flight history, the modifications that were necessary to make the device work, and the tests performed to verify its functionality.

INTRODUCTION

The Pressure Modulator Infrared Radiometer (PMIRR) is a nine-channel limb and nadir scanning instrument on the Mars Observer Spacecraft, designed to study the geosciences and climatology of Mars. It achieves high radiometric precision by means of a two-point calibration cycle. The first calibration source is an external, flat aluminum target disk that views cold space. The second source is a 300-degree Kelvin blackbody target internal to the instrument. This

---

*Jet Propulsion Laboratory, California Institute of Technology,
4800 Oak Grove Drive, Pasadena, California 91109

target's surface has a high emissivity coating (Martin Marietta Optical Black) on a 6061-T651 aluminum alloy substrate with concentric V-groove rings for a predicted emissivity greater than 0.97 in the wavelength range of 6 to 50 microns. The target is driven into the optical path of the detectors in front of the prime focus of the telescope every 20 minutes for 8 seconds during the mapping phase of the spacecraft mission.

In an effort to minimize the development cost and time, the drive mechanism of the Focal Plane Shutter (FPS) (Figure 1) was specified to be used for driving the Blackbody Calibration Target. The principles of this drive mechanism are illustrated in Figure 2. A capacitor discharge into a wound bobbin generates a magnetic field that repels the detents of a permanent magnet about its pivot from the starting position until they are attracted to, and then held in the actuated position. A second winding when energized reverses the direction of rotation. The mechanism is a bistable magnetically latching device with a long history of successful flight applications on the Mariner, Viking, Voyager, and Galileo Missions. However, the drivers were originally designed to actuate thin aluminum shutter blades with a mass of no more than 0.5 grams. The mass of the Blackbody Calibration Target had to be greater than 1.97 grams to satisfy a temperature stability requirement of 0.02 degree Kelvin or less change in 64 seconds. Because thermal stability is a critical parameter in calibration, a temperature sensor was required to be placed on the back side of the Blackbody Target, which increased the mass of the target. Also, the cabling for the temperature sensor placed an additional torque load on the driver.

DESIGN CONSTRAINTS

The constraints imposed by the project were as follows. The power supply for the coils had to be supplied from a discharging capacitor because the spacecraft cannot tolerate a sudden current drain. The drive mechanism of the FPS had to be used to actuate the device with an existing mounting interface, since the optical bench had already been fabricated. Any modifications to the existing mechanism had to fit within an extremely tight envelope (Figure 3). The Blackbody Calibration Target required a Platinum Resistance Temperature (PRT) sensor with four wire leads shielded from electromagnetic interference. The mechanism had to operate for a minimum life of 50,000 cycles during a two-year mission period. The target had to completely cover the field of the view of all detectors during calibration cycles and retract completely away from the optical paths when stowed. The target had to have a positional repeatability tolerance of fewer than 0.7 mm. No chance of a bounce back could be permitted, since failure of the Blackbody Target to retract from the optical path is a catastrophic failure for the entire instrument. By choosing an existing mechanism for this task, no fail-safe features could be incorporated. Additionally, the hardware delivery date for integration to the instrument left no schedule margin for development of an entirely new mechanism.

DRIVE MARGIN TESTS

Margin tests were conducted by using a drive mechanism identical to the flight design. The Drive Arm, Blackbody Target, and the cabling from the temperature sensor were simulated. Tests were conducted on the drive mechanism by using a setup similar to one shown in Figure 4. Three photoelectric sensors were positioned to indicate the two ends of travel and the midpoint of travel. A thin flag was attached to the Drive Arm, which triggered the position sensors as the arm moved. A sample of the typical test result is shown in Figure 5. The bottom trace shows the capacitor voltage discharging into the coils. The top trace shows the photoelectric sensors indicating the position of the target. When the flag attached to the Drive Arm triggered a photoelectric sensor, the voltage output from the sensor jumped from 0 to 5 volts. The magnitude and the number of bounces were deduced from the number of peaks and the distance separating them.

Extensive tests were conducted using this setup for targets of various masses. The results of these tests show that the Drive Arm bounced when the mass of the target was greater than 1 gram. The bounce problem occurs when the momentum generated by the arm and the target during actuation overcomes the latching force of the magnet. In addition to generating greater momentum, driving a larger mass has the compounded effect of lengthening the actuation time. Because the voltage from the capacitor decays quickly after a slow actuation, the coil provides little holding force to assist the magnet in overcoming the arm/target rebound at the end of travel. With a target mass less than 1.5 grams, the bounce merely lengthened the settling time; the Drive Arm always ended up where it was supposed to go. However, with a target mass greater than 1.5 grams, the drive arm would bounce overcenter to its starting position.

The torque effects of the magnetic field on the Drive Arm were characterized using a force transducer (Figure 6). While running a constant voltage from a power supply through the coil, the torque on the Drive Arm was measured at different arm positions. The effects of the cabling were characterized using the same method without the magnet at the Drive Arm pivot point. It was found that, for coil voltages less than or equal to 5 volts, the magnitude of the torque from the cabling is greater than the torque generated by the coil.

DESIGN MODIFICATIONS

More Powerful Drive Electronics

The initial drive electronics initially provided a 33-millisecond discharge from a 660-microfarad capacitor charged to 50 volts. With this drive source, it took 30 milliseconds for the Drive Arm with a 2-gram target to reach the actuated position. Since the 2-gram mass caused bounce, the magnetic field generated by the coil had dissipated even though the Drive Arm was still moving. Thus, a bounce greater than 50 percent of total travel would cause the Drive Arm to settle at the position from which it initially started.

The first modification to the design was to the electronic driver. The pulse length was increased from 33 to 100 milliseconds and the capacitance was doubled from 660 to 1320 microfarads. By increasing the length of the pulse, there would still be a significant magnetic field directing the Drive Arm to the correct orientation during the bounce. Although doubling the capacitance increases the momentum that must be dissipated, it also reduces the rate of time decay, so that the magnetic field generated by the higher voltage helps to attract the magnet detents to the right position during settling. The electronic chassis that houses the capacitors physically limited any additional increase in power.

Flex Print Cabling

In order to minimize the torque effects of the PRT cables across the Drive Arm pivot, a dynamic flex print circuit was designed at Jet Propulsion Laboratory and fabricated at Tayco Engineering in Long Beach, CA. The leads from the PRT and the twisted quad shielded and jacketed (TQSJ) cable were envelope restrictions of the Blackbody Target Mechanism precluded incorporation of useful bumpers.

Another momentum dampening method investigated was inspired by the dead-blow hammer (Figure 8). This damper involved filling an enclosed cavity with 0.76-mm diameter stainless steel balls. The smallest readily available balls were used since they could contour to the cavity for higher packing density. Although balls made of materials of low coefficient of restitution, such as lead, would have improved damping characteristics, the advantages in easy procurement of ball bearing parts with certification for spacecraft application and the success of stainless steel balls during prototype testing discouraged a lengthy investigation on material choice. Individually, each ball would have very little momentum so that the effects of the random motions at the latched positions in a microgravity environment would be minimized. Collectively, the balls had enough counter momentum to dissipate the excessive kinetic energy in the Drive Arm before it bounced out of the designated position. On the prototype setup, this method dampened the bounce more effectively than other methods. More importantly, the bounce-back was completely eliminated.

The allowable envelope for the calibration target mechanism restricted the volume of the cavity for the dead-blow balls. With the given cavity, the quantity of the balls for the optimal dead-blow effect was determined empirically by using the drive margin test setup. Because the dead-blow effect worked so effectively, the capacitance of the test drive electronics had to be decreased to create bounce that could be analyzed. By iterating the test with the cavity full of different amounts of balls, and comparing the bounce that each produced, the optimum amount was found. For the application in the Blackbody Target Mechanism, this optimum amount occupied 85 percent of the volume in the cavity.

CONCLUSION

Despite the long history of successful flight applications, retrofitting the Focal Plane Shutter Drive Mechanism for use on a new instrument with a different set of requirements demanded much more effort than was originally anticipated. The modifications necessary to reliably operate the Blackbody Calibration Target Mechanism by the use of existing inherited hardware required design changes in the drive electronics, incorporation of flexible integrated into a Flex Print Assembly (Figure 7). The flexible part of the cable was made of four 0.07- x 0.25-mm copper conductors laminated with FEP Teflon in between two pieces of 0.03-mm thick Kapton film. The leads from the PRT and the TQSJ cable were welded to the conductors internal to the Kapton laminate. This design uses the same fabrication techniques used for manufacturing film heaters. The flex print design minimizes the torque loading on the drive system because the cable acts as a weak spring; the spring is oriented so that it assists the drive mechanism when restowing out of the optical path. Flex print cables have demonstrated high reliability and long life in many military and commercial applications.

To meet the requirements for shielding the conductors, the flex print was vacuum deposited with gold. Since the flex print has to withstand dynamic flexing throughout the mission, there is a risk of gold flaking off. In order to be certain that there is no potential for particulate contamination, the vacuum deposited gold had to undergo a tape pull test without any residue on the tape. The only method attempted that left no residue on the tape test involved exposing the Kapton to an ion beam and vacuum depositing it with titanium prior to vacuum depositing it with gold. The shield on the flex print was electrically bonded to the shield on the TQSJ cable through a hole in the Kapton which exposed the shield of the TQSJ cable. Although the vacuum deposited gold connects the shield on the TQSJ cable to the surface of the Kapton, an electrically conductive adhesive was also used to ensure continuity.

Eliminating Excessive Rebound

The bounce problem was addressed by experimenting with different methods of damping. Initially, the drive margin tests were conducted with a stiff arm to minimize the bending (stored energy) and to increase the natural frequency. When the bounce became a serious reliability concern, a two-piece arm coupled with an elastomeric damper was tested in place of the stiff arm. It was hoped that the elastic deformation of the rubber would absorb and dissipate the kinetic energy. Although this design reduced the bounce, it did not eliminate it or prevent bounce-back of heavier targets. More important, the positional accuracy of the target was significantly compromised.

In other designs using a drive mechanism similar to the FPS, end of travel bumpers were used to dampen out the excessive momentum. However, the cabling, and incorporation of a damping method. The constraints imposed by the instrument were met by using a dynamic flex print cable for the PRT sensor and by using a dead-blow damper on the back side of the Blackbody Target. The dead-blow damper uses the momentum of the free-floating balls inside a cavity to counter and dissipate the momentum stored in the Drive Arm and the target when actuated. The drive margin tests using the dead-blow damper demonstrated consistant results with minimal rebound and no bounce-back.

The work described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

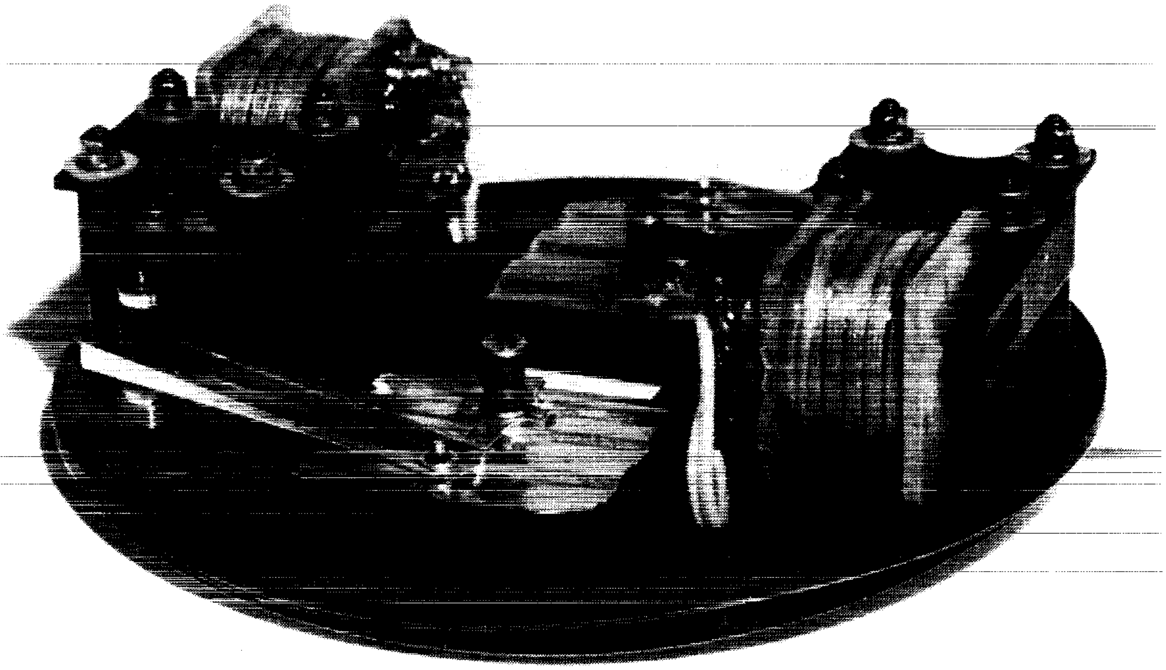
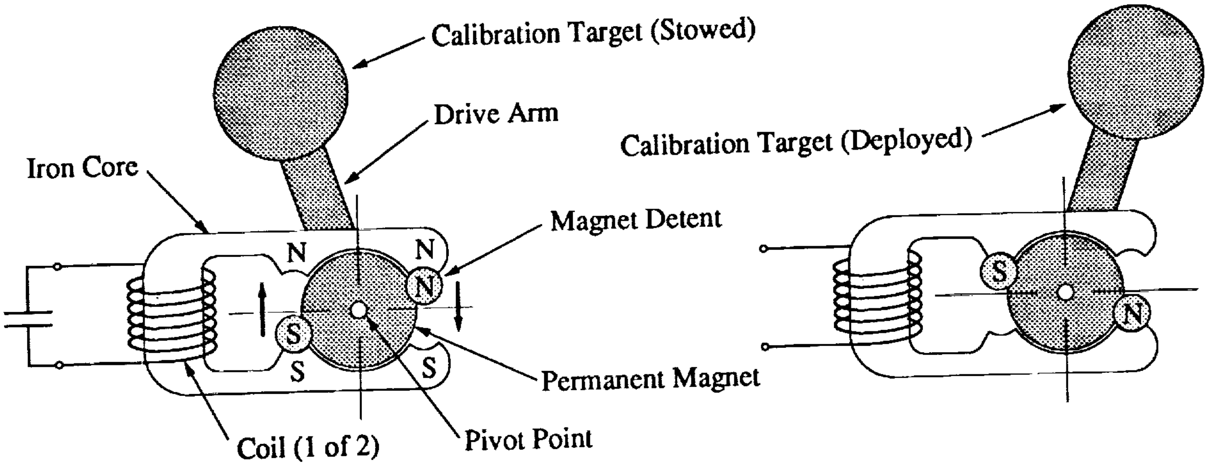


Figure 1: Focal Plane Shutter Mechanism. The mass of each aluminum blade is less than 0.5 gram.



The Detents are repelled from their initial position when the current flowing through the coil generates a magnetic field in the iron core.

The magnetic force causes the calibration target to rotate about the pivot point until the detents have settled. Detents are magnetically latched to the iron core until the next actuation command.

Figure 2: Drive mechanism principle of operation.

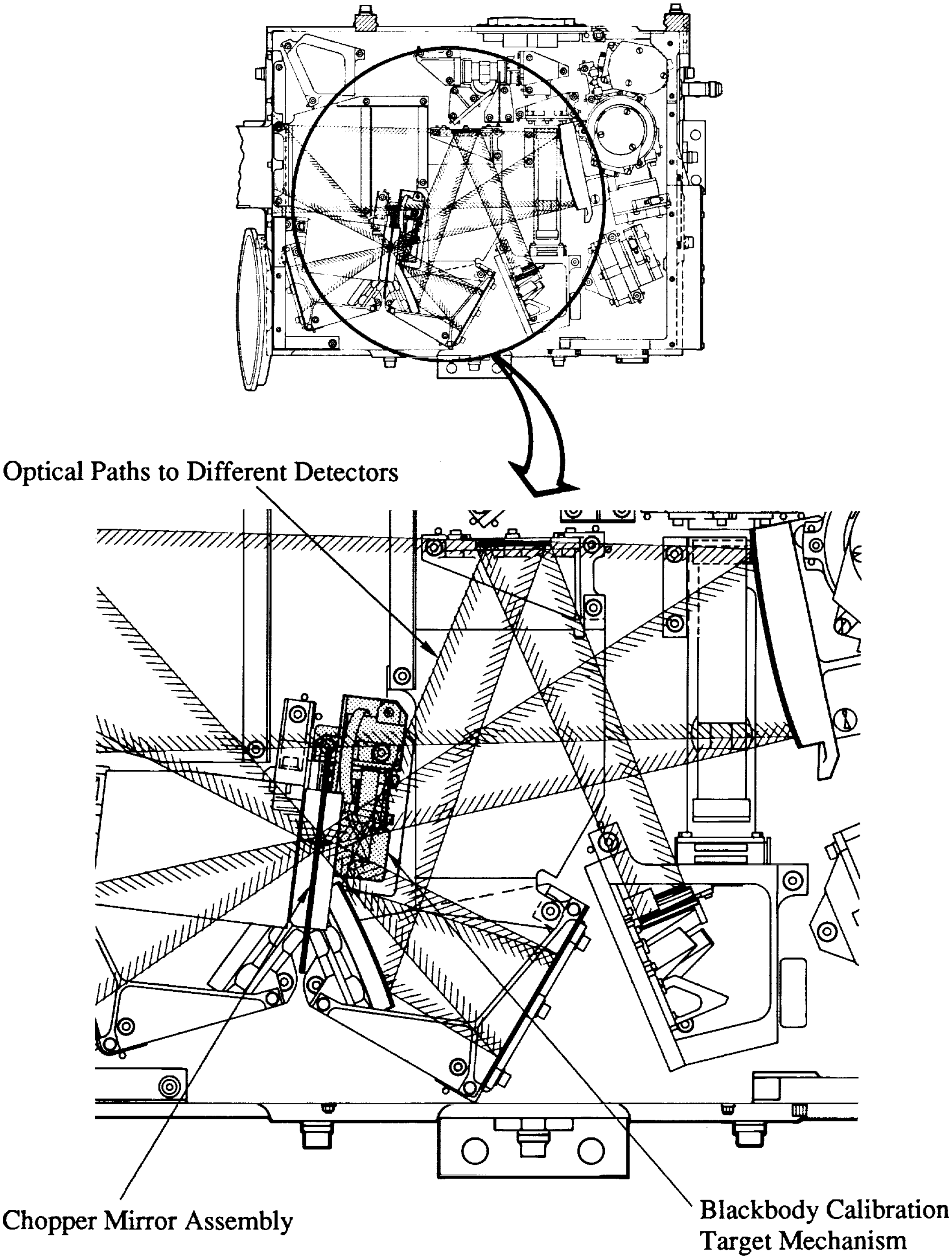
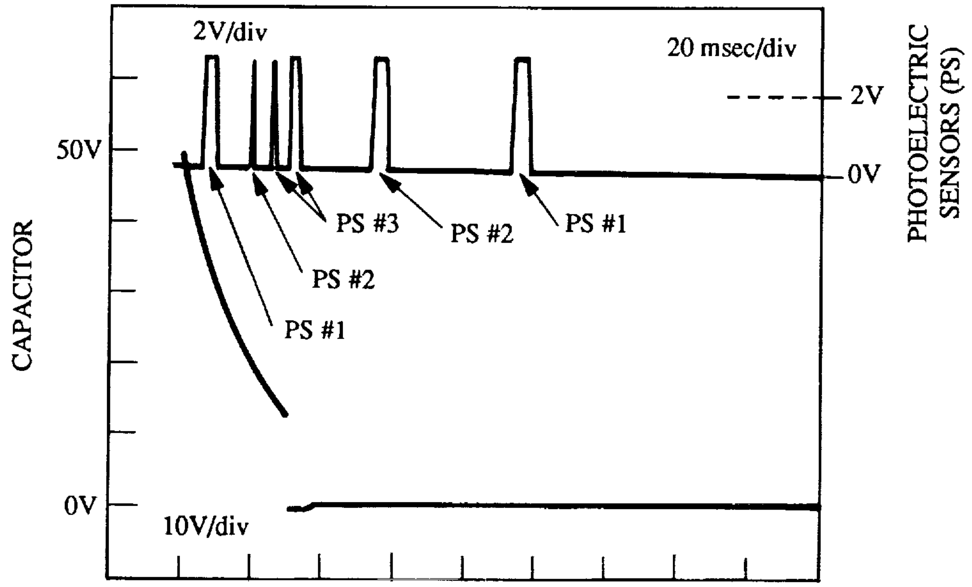


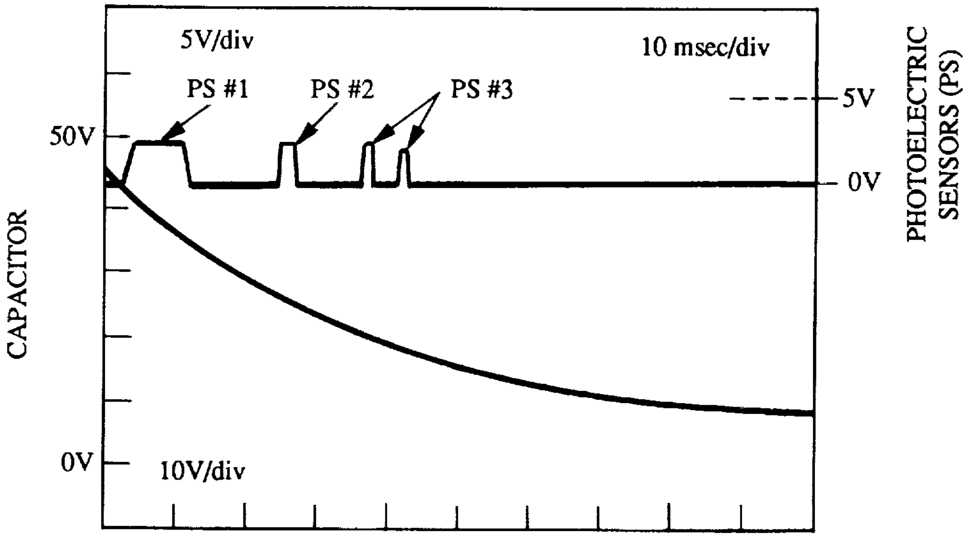
Figure 3: Envelope restrictions on Blackbody Target Mechanism.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Figure 4: Drive Margin Test Setup.



Without any modifications, the momentum generated by a target mass of 2 grams caused it to bounce back to the position from which it started.



With all the modifications incorporated, rebound was minimized and bounce-back was eliminated.

Figure 5: Sample of Typical Drive Margin Test Results.

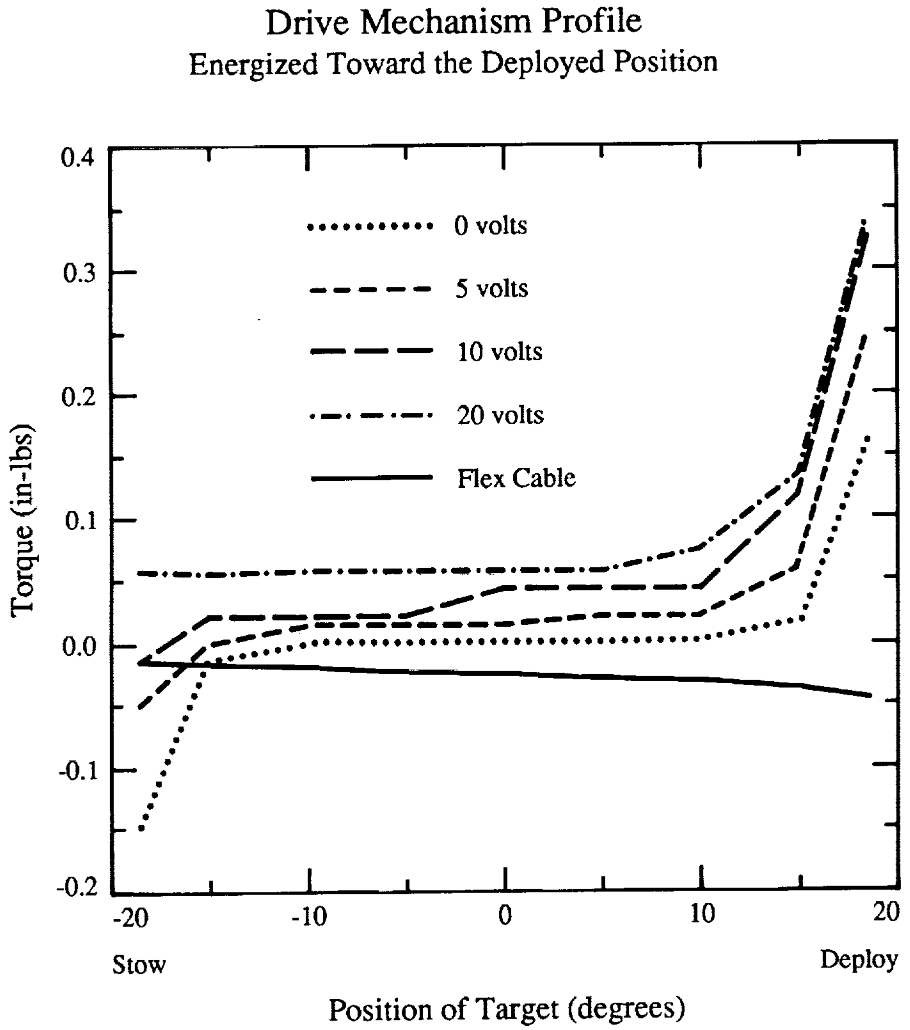
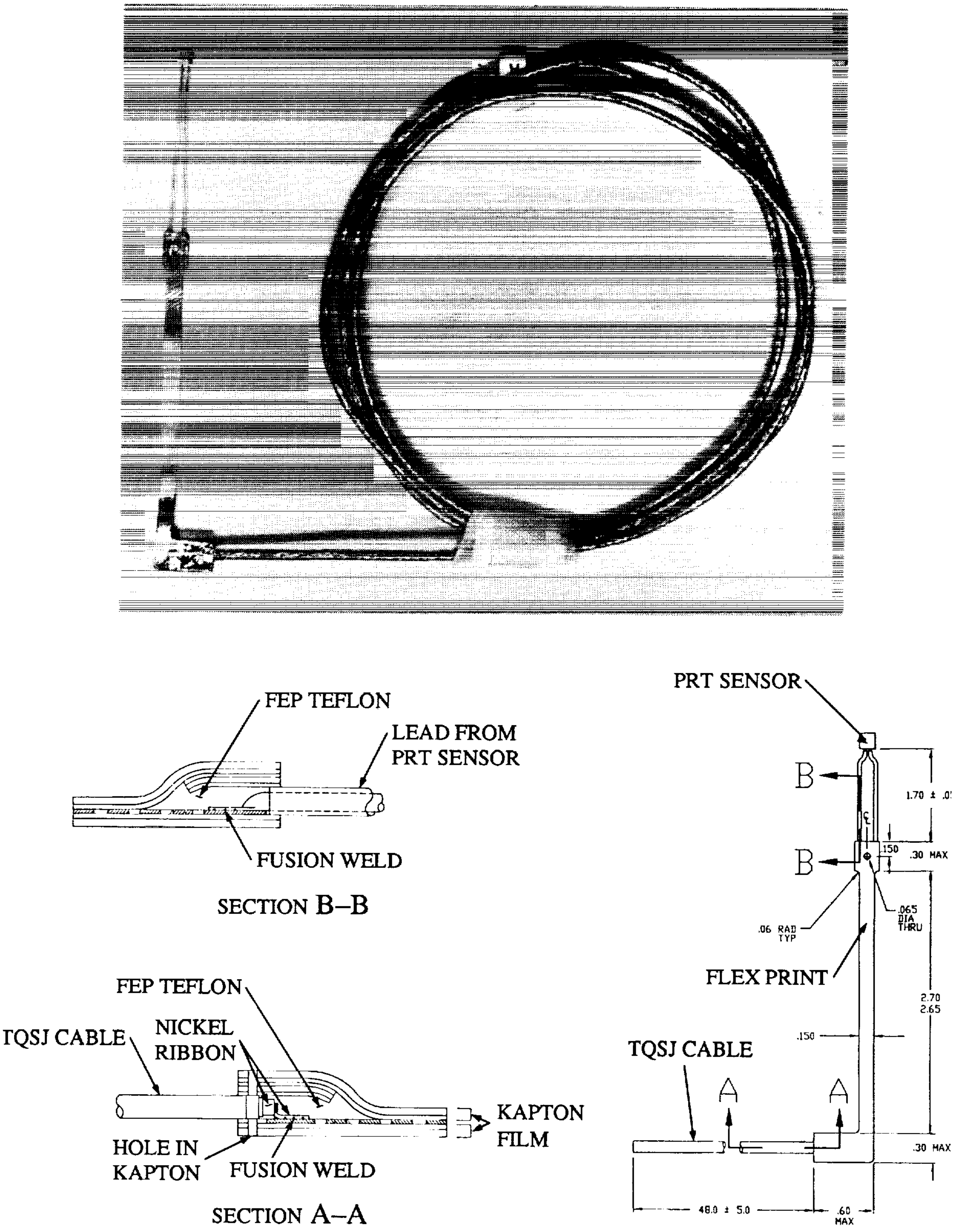


Figure 6: Characterization of magnetic forces on Drive Arm.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



Units are presented in inches.

Figure 7: Flex Print Cable Assembly.

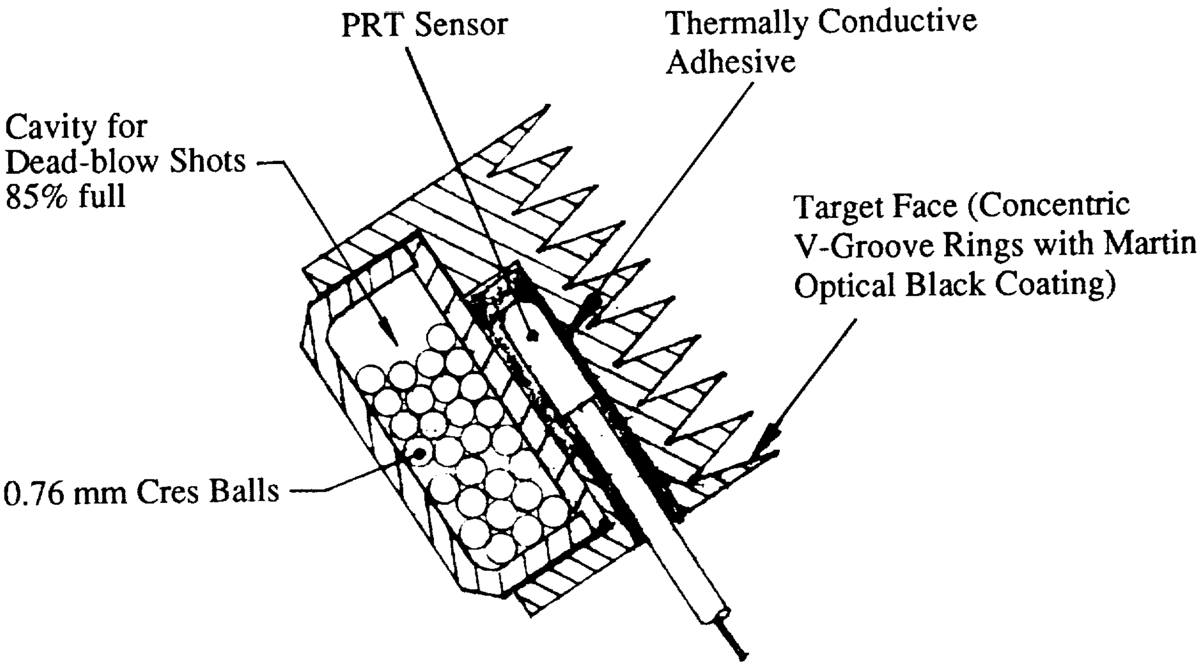


Figure 8: Dead-blow damper incorporated into the target.

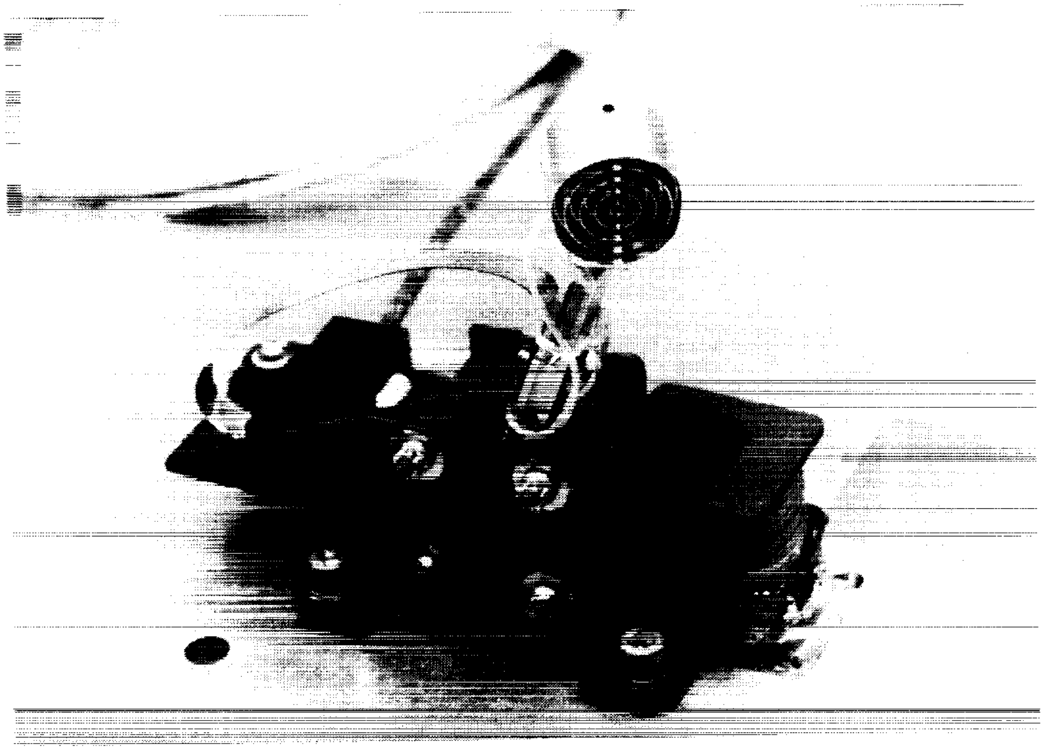


Figure 9: Front view of Black body Calibration Target Mechanism prototype unit without Martin Optical Black coating on target surface.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH