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SHUTTER MECHANISM FOR CALIBRATION OF THE CRYOGENIC DIFFUSED INFRARED BACKGROUND EXPERIMENT (DIRBE) INSTRUMENT

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This paper describes the design requirements, the design, the assembly and alignment, and the test program for a shutter mechanism which must operate at cryogenic temperature and draw less than 1.0 milliwatt. The design solution to meet these requirements is a device that positions a mirror with repeated accuracy, has no wearing surfaces, and operates at 2.0^{o}K. The unique feature of this device is the simplicity of the mechanism, thus obtaining high reliability.

INTRODUCTION

The DIRBE is one of two cryogenic instruments aboard the Cosmic Background Explorer (COBE) spacecraft. DIRBE will measure the diffused radiation of the universe in the wavelength region between 1 and 300 microns. The low signal levels require the use of an instrument whose "self emission" is less than that which is being measured and dictate an instrument operating temperature of 2.0°K. Since the instrument requires in orbit calibration, a requirement became apparent for a shutter mechanism which upon command would move a blade into the first field stop of the optical system, thus blocking the radiation that enters the instrument from space, and simultaneously position a flat mirror which is part of the internal reference source (IRS). This allows the known radiation from this source to be used to calibrate the instrument. Figure 1 shows the arrangement of the optical components within the DIRBE instrument. Highlighted is the field stop that has a square opening that measures 7.9mm by 7.9mm (.311 in. by .311 in.); the shutter mechanism located at the field stop; the IRS, a 32 Hz chopper; and three detector assemblies.

REQUIREMENTS

The following requirements are summarized and briefly discussed:

a. Provide a radiation seal to the detectors when in the closed position.

b. Reflect radiation from the IRS to the detectors when in the closed position.

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c. Survive 50,000 actuations (ground test and on orbit).

d. Withstand thermal cycling between room temperature and 2.0°K.

e. Require a maximum power dissipation when energized $\leq$1.0 milliwatt.

f. Provide a fail safe mechanism (electrically fails open).

g. Incorporate dual coil windings and dual electronics for redundancy.

Since the shutter mechanism is required to block out the incoming radiation and simulataneously position a flat mirror to reflect radiation from a known source, the shutter/mirror combination would have to be positioned with repeated accuracy.

The instrument is expected to be calibrated as many as five times per orbit early in the 1 year mission and trailing off to perhaps only once per orbit in the latter part of the mission. The actual number of shutter actuations could be nearly 20,000. The design requirement for 50,000 actuations would be verified with an accelerated life test at liquid helium temperature to demonstrate that this requirement was achieved.

A likely failure mode for a mechanism to operate at 2.0^{o}K is the cool down survival itself, in particular the windings. The requirement for dual coil windings will alleviate this potential problem. This mechanism will therefore be exposed to several cool down cycles from room temperature to 2.0^{o}K to verify the mechanism's integrity to meet this requirement.

The lifetime of the flight liquid helium dewar is highly dependent upon the heat dissipation within the instrument. The power budget for the DIRBE instrument alloted 1.0 milliwatt maximum power to operate the shutter mechanism.

A shutter that would fail in the closed position would be catastrophic. It is therefore extremely important that in case of an electrical failure (power off condition) the shutter will return to its open position.

DESIGN

Common motors and solenoids could not be used because of the rigid power and temperature requirements. In addition there existed a tight envelope constraint that had an influence on the final size and shape of the mechanism.

The shutter was designed to move a mirror over a distance of 17.0mm (.67 in) and close off the field stop that has a 7.9 mm (.311 in) square opening. The shutter mechanism designed is essentially a magnetically actuated mechanism (Figure 2). It consists of two curved pole pieces and a metal bobbin manufactured from highly purified iron with low hysteresis and high flux density properties. There is also a flexible tine made of high strength tool steel (SAE 1074 steel) to which an aluminum flat mirror is attached. The bobbin is wound with superconducting wire (niobium titanium wire) which is then vacuum impregnated with FORMVAR to support the windings. The wound bobbin forms two coils which can independently activate the device, thus meeting the redundancy requirement. The wound bobbin is sandwiched between the two pole pieces and the air gap is located at the curved surface. The curve was derived from the equation of a cantilevered beam uniformly loaded in bending. Upon activation, the steel tine is pulled toward the curved pole surface closing the airgap (zipper effect) and taking the shape of the curved pole pieces. To initiate this action, the pull-in current to close the shutter is 45 to 50 milliamps (MA) for a 200 millisecond pulse, but is reduced to 10 MA to hold the tine and shutter in place. To assure release after the current is removed, a small gap is maintained with a .06mm (.002 in) thick plating of a nonmagnetic coating of copper and gold on the contact area of the pole pieces. The spring action of the tine will return it to the open position.

ASSEMBLY/ALIGNMENT

The two pole pieces and bobbin which are made of pure iron are hydrogen annealed at 1200°K - 1275°K for 4 hours to produce the low hysteresis and high flux density that is required. The bobbin and a spacer sandwiched between the 2 pole pieces accurately locate the 2 curved surfaces with precision. The tine holder with tine attached is mounted to one of the pole parts and is aligned by positioning the tine tangent to the curved pole pieces at the bottom. This condition is achieved by measuring the minimum current required to close the tine. The tine holder is then drilled and pinned at assembly to the pole piece. The shutter mechanism is then mounted to the field stop support. By shimming between the mechanism and field stop support, the shutter blade/mirror is positioned parallel to the field stop with a .076mm (.003 in.) clearance gap (Figure 2). The mechanism is drilled and pinned at assembly to the field stop support. Pinning of the mechanism provides a dual purpose. It prevents movement of the mechanism during launch vibration and it permits disassembly and assembly while maintaining the original alignment.

The minimum achievable gap obtained (.003 in.) will maximize the effectiveness of the photon sealing. For added assurance to block out the incoming radiation, a shutter retainer was added to produce a labyrinth type of seal (noncontacting) along 3 sides of the field stop, which in effect, provides a more tortuous path for photon leakage (Figure 3).

TEST PROGRAM

The shutter mechanism has undergone a series of tests to verify the following:

- cool down survival
- functional performance at $8.0^{o}K$
- thermal cycling survival
- structural integrity
- mirror position repeatability
- photon sealing effectivness
- 50,000 cycle life test

The mechanism has been cooled several times in a liquid helium dewar to less than $8.0^{o}K$ and has functioned successfully.

Structural vibration tests have been conducted on the mechanism at room temperature and $8.0^{o}K$ along three orthogonal axes to the mechanism, to the following levels:

AXIS	X	Y	Z
quasi-static	15.0 g's	15.0 g's	15.0 g's
random	7.4 grms	5.5 grms	5.2 grms

Verification of the shutter mechanism's capability to accurately repeat mirror position and to block out external radiation to the instrument was accomplished during a complete DIRBE instrument systems test. With the shutter mechanism integrated in the instrument and optically aligned with the internal reference source (IRS), the instrument was cooled to $2.0^{o}K$ in a liquid helium dewar.

The shutter mechanism was actuated several times during this test, thus blocking out the incoming radiation from a DIRBE external calibrator, a piece of support equipment used to simulate in-orbit radiation from space. Measurements made by the flight detector assemblies within the instrument showed that the shutter, when closed, reduced the incoming signal by greater than 200,000 counts to one. With the shutter closed and the IRS energized, the flight detectors measured the calibrated signal with excellent repeatability each time the shutter was actuated. The data from this instrument systems test was verification that the shutter mechanism met the performance requirements.

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A life test is presently being prepared for the shutter mechanism (a second unit) to demonstrate its endurance capability. This test will be an accelerated life test performed at 8.0^{o}K. The shutter mechanism will be actuated once every 5 seconds until 50,000 cycles are reached.

CONCLUSION

A shutter mechanism was developed to accurately position a mirror, block out the incoming radiation to the instrument, and operate at 2.0^{o}K. This mechanism could be adapted for use with other simular instruments or applications.

ACKNOWLEDGEMENT

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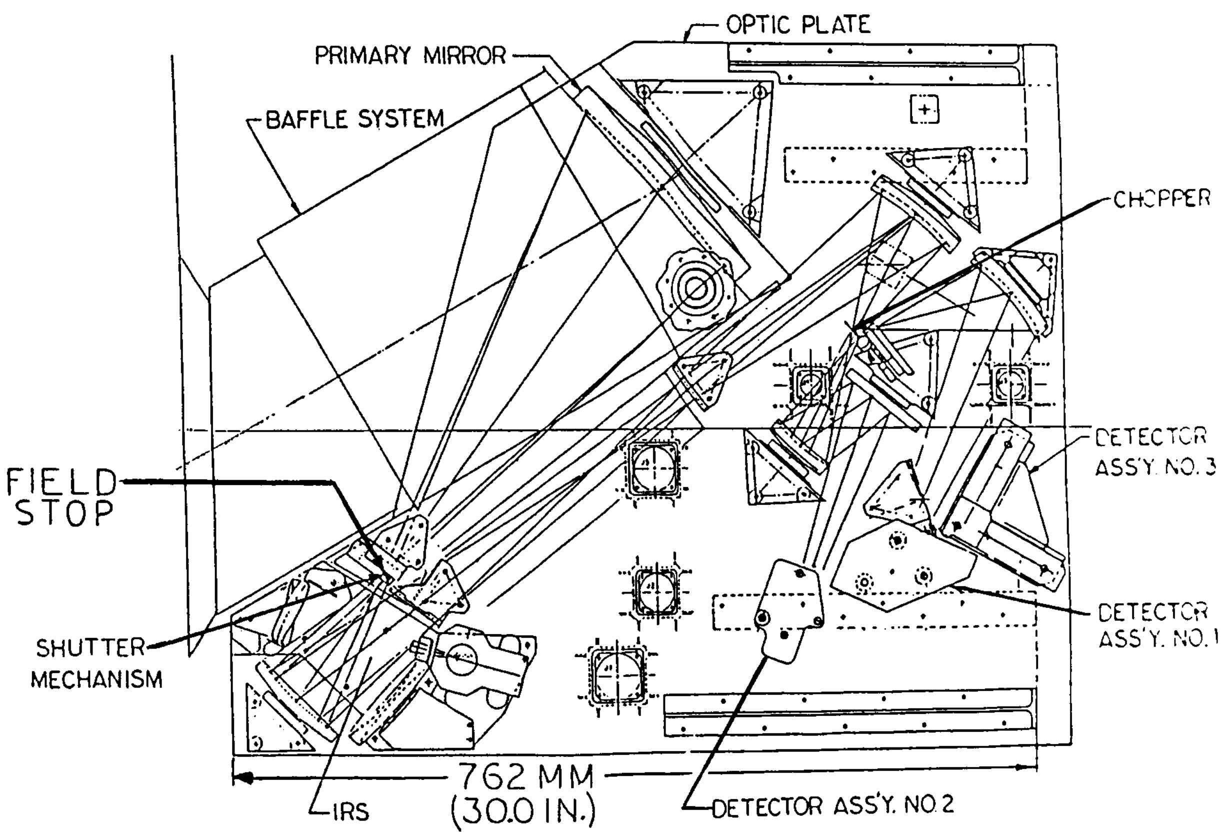

Figure 1. - DIRBE.

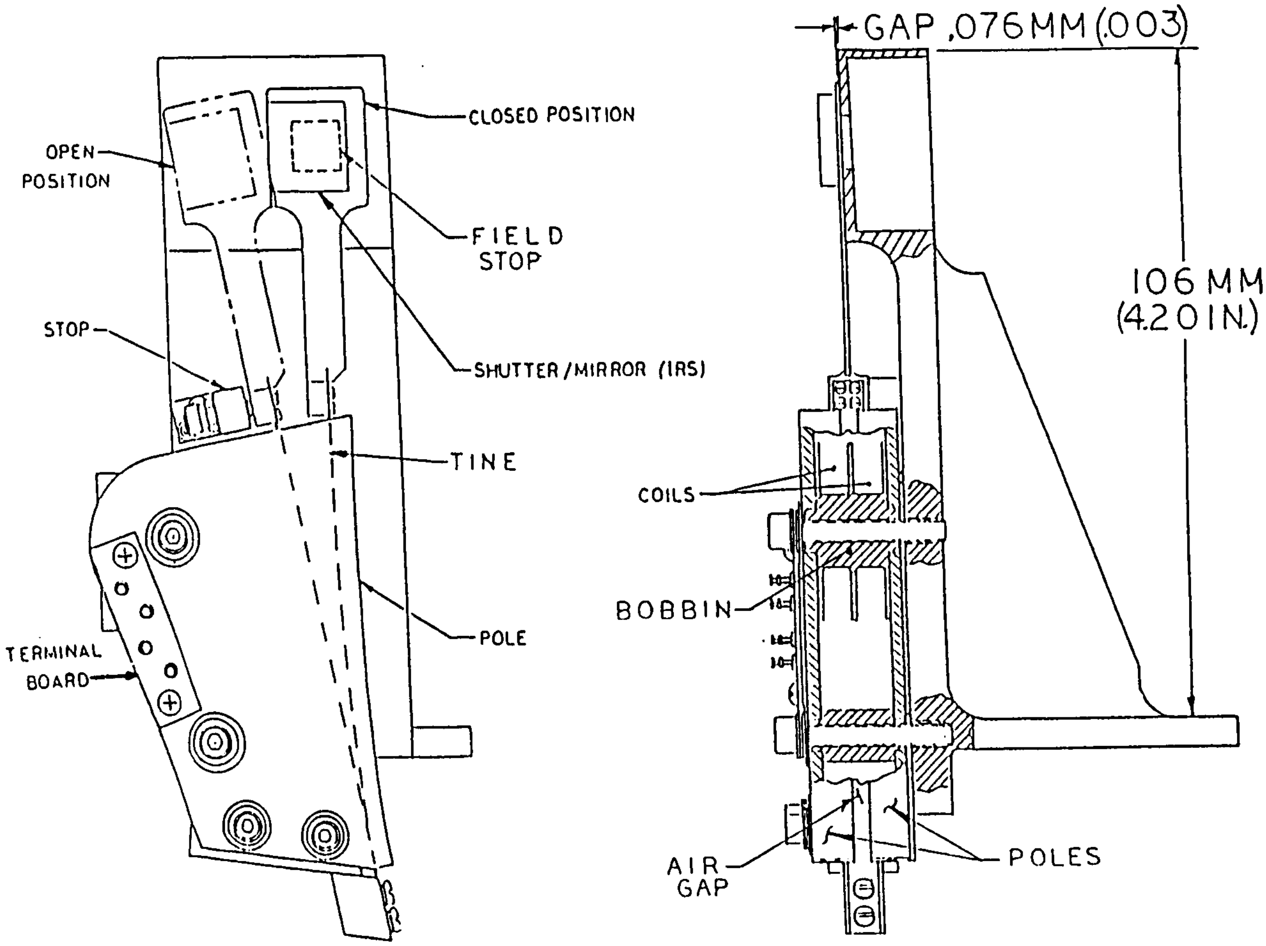

Figure 2. - Shutter mechanism.

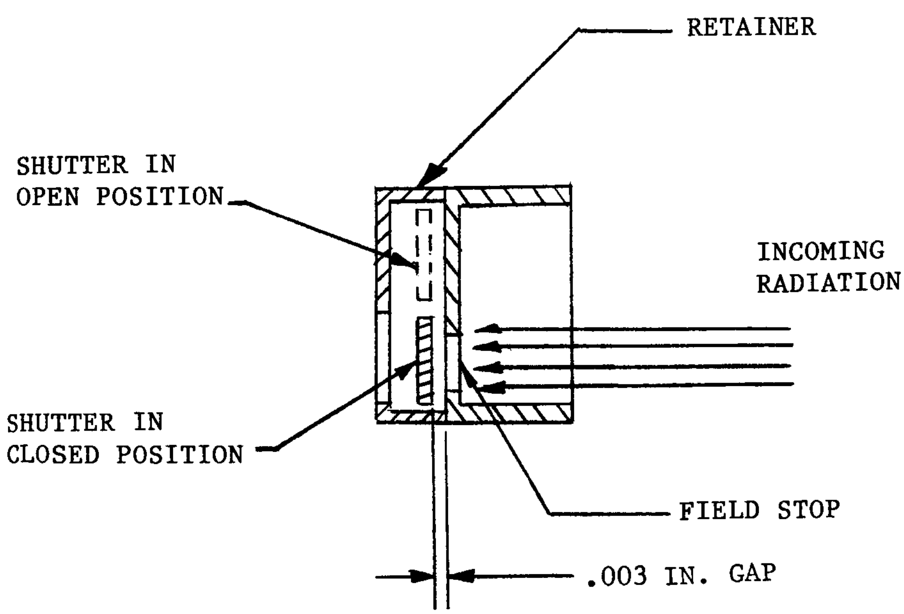

Figure 3. - Photon seal.