LT 21

Proceedings of the 21st International Conference on Low Temperature Physics
Prague, August 8-14, 1996
Part S5 - Techniques and applications: Instrumentation

A Cryogenic Optical Telescope for Inertial Pointing in the Milli-arc-sec Range

Suwen Wang, D.-H. Gwo, R.K. Kirschman and J.A. Lipa

Hansen Experimental Physics Laboratory, Stanford University, Stanford, CA 94305, U. S. A.

We report the test results of the prototype telescope which is part of a system that provides the inertial reference frame for Gravity Probe B. The fused silica star-tracking telescope, which has an effective focal length of 3.8 m at room temperature, experienced a 5 cm focal position shift upon cooling to 4.2 K. A method to compensate this focal shift is described. The photo sensor for the telescope uses Si PIN photodiodes and Si JFET preamplifiers, all mounted on a miniature thermal platform to accommodate the approximately 80 K operating temperature of the JFETs. An electronics noise level of 17 aA/(Hz)$^{1/2}$ at 10 Hz has been achieved. At this noise level, photon noise dominates for 5th magnitude candidate guide stars selected for the mission.

INTRODUCTION

By the prediction of L.I. Schiff [1] based on general relativity, a gyro in a 650 km altitude polar orbit has a geodetic precession of 6.6 arc sec/yr. and frame dragging precession between 33 and 42 marc sec/yr. depending on the gyro spin axis orientation. One major goal of the Gravity Probe B, the Relativity Mission, is to measure the former effect to 0.01% and the later to 1% with precision orbiting gyroscopes [2]. To achieve such precision, a stable reference frame is required. A cryogenic star tracking telescope, which is rigidly attached to the gyroscope readout assembly and a spacecraft pointing system are used to provide the reference pointing direction. A guide star with accurately measured proper motion is also needed.

The prototype GP-B telescope [3][4], which has an effective focal length of 3.8 m and an aperture of 15 cm with 7 cm central obscuration, is of a modified Schmidt-Cassagrain type with primary, secondary, tertiary mirrors and a corrector plate. The converging guide star light beam is split into two and each part is bisected at the focal point by sharp roof edge mirrors placed so as to provide orthogonal pointing signals. Each portion of the bisected star image is transferred onto a photo sensor. The difference of the sensor outputs gives the deviation of the telescope from zero pointing.

The telescope is built entirely from fused silica, the components assembled by using optical contacting to minimize cryogenic distortions.

The photo sensors are made from dies of Si PIN photodiodes and Si JFET's mounted on the same miniture platform. Since Si JFET's will not work at 2 K, the nominal operating temperature of the telescope, the platform is thermally isolated from the 2 K environment by gold-coated polyimide standoffs. A few hundred μW of heating power to the platform brings the temperature up to the 70 K range. To achieve low noise in the preamp, Si JEFT's were custom made by NASA Goddard to optimize the performance at low temperatures [5].

TELESCOPE TESTING

The telescope was tested for image quality using an optical system called an artificial star. This facility consists mainly of a vacuum chamber which houses a star simulating parallel beam and an autocollimated reference beam. Attached to the star is a low-temperature probe which houses the telescope and a set of four windows. The entire system is suspended with a mechanical low pass filter with a fundamental frequency of 1 Hz. The reference beam, in combination with the reference mirror on top of the telescope and a servo mechanism, dynamically locks the telescope to a nominal zero pointing direction. The star beam can be independently steered by stepper motors in two orthogonal directions within a range of 10 arc sec with a 1 marc sec interval. Also the probe can be tilted with respect to the star beam by stepper motors within a range of 1 degree with a step size of 0.2 arc sec; this tilt mechanism is used for alignment and coarse scans of star image across the focal plane.

As the star beam is scanned such that its image sweeps across one of the roof edges, the signal from a single photo detector is as shown in Fig. 1(a) and (b). The solid line is the prediction for a perfectly focused image; the dashed line shows an actual scan at 4.2 K.

he enlarged image size is because the focal position ıifted axially by 5 cm. This focal position shift is elieved to be caused by differential thermal contraction etween adjacent fused silica components of the elescope. To measure the focal position shift, we use a i PIN diode quad cell in place of the roof edge image ivider assembly. Unlike the roof edges, the quad cell an be moved in the axial direction to determine the osition of best focus. The dash-dotted line in Fig. 1 hows an image scan at 4.2K with the quad cell sensing urface at the optimal focal plane. The residual image ize enlargement appears to be due to non-focal cryogenic listortions of the telescope components and windows.

TELESCOPE READOUT TESTING

A separate apparatus was used for testing the noise erformance of the telescope readout electronics. In this ıparatus, two independent light beams can be focused nto a vacuum can in which the photo sensor assembly s mounted. Each focused light spot falls onto one of he two photo diodes. At temperatures below 100 K, the

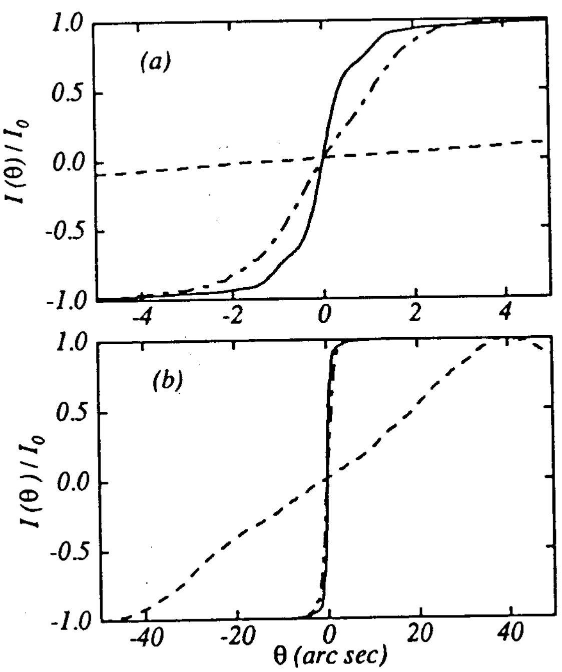

Fig. 1 Telescope Angular Response

dark current of the photodiodes is less than 50 aA. Since a current integrating method is used, the photo sensor output voltage V increases linearly with time. The photo current is $I = C(dV/dt)$, where C is the effective capacitance seen by the photodiode. The voltage is reset at a 10 Hz interval and I measured for each integration period between resets. To determine the noise level in the current estimates, we collected slope data for 1000 integration periods. This data was converted to a histogram of current values and fit with a Gaussian. The σ of the fit gives the rms noise level.

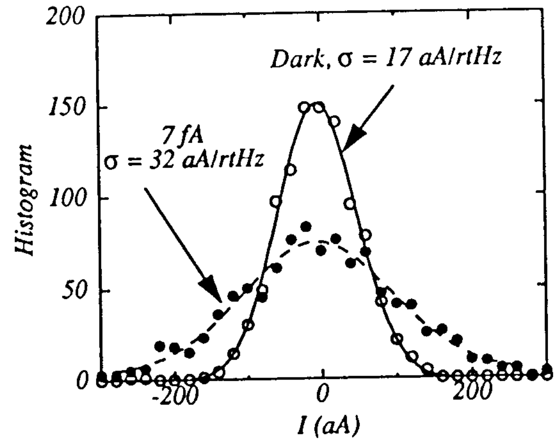

Fig. 2 Photon Noise Limited Electronics

Fig. 2 shows the histogram data with light which produces 7 fA of photo current and that without light. A preliminary calculation shows that for a 5th magnitude guide star, each photodiode would collect at least 10 fA of photo current. The measurements show that our electronics noise is significantly lower than photon noise.

SUMMARY

The prototype GP-B telescope has been tested at 4.2 K along with its readout system. The telescope showed a 5 cm focal position shift at 4.2 K. For the flight telescope, we have chosen to make it from a single boule of fused quartz of high homogeneity in an effort to minimize the cryogenic focal position shift. Initial measurements with this device indicate that its focal position shift is less than 2.5 mm. The prototype telescope readout provides photon noise limited performance for the 5th magnitude candidate guide star.

This work supported by NASA Contract Numbers NAS8-36125 and NAS8-39225.

REFERENCES

[1] L.I. Schiff, Phy. Rev. Lett. 4, 215(1960)
[2] B. Muhlfelder, et al., Proc. 7th MG, pg. 1545(1996).
[3] C.W.F. Everitt, et al, SPIE 619, 89(1986).
[4] J. A. Lipa, et al, SPIE 1765, 85(1992).
[5] R.T. Goldberg, et al, The Elec. Chem. Soc. Proc. 95-9, 429(1995)