ROTATION STAGE 02040-075

Spartan Infrared Camera for the SOAR Telescope

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We measured the looseness and response of rotation stage SN02040-075 at room temperature and 77 K. Looseness, defined as the angle perpendicular to the rotation axis at which the rotation stage resists radial torque, is 2.8 and 0.4 mrad peak-to-peak at 292 K and 77 K respectively. The response of the rotation stage to radial torque is 60 μrad/N/m at room temperature and 40 μrad/N/m at 77 K.

1 Purpose

Phytron/Micos PRS110 rotation stages drive all of the mechanisms in the Spartan Camera, and the most exacting mechanisms are those holding mirrors, where the requirement is 12 μrad to maintain pointing within ½ pixel. Rotation stage SN02040-075 is very loose at room temperature: with a small torque, it tilts 1.8 mrad, which is 150 times greater than the requirement. This test aims to measure the looseness at 77 K.

Biel & Loh 2002,[1] measured the prototype, unnumbered rotation stage and found the stage is not loose and the response is 7 μrad/N/m at 77 K and 2 μrad/N/m at 290 K. The procedure for keeping the rotation stage dry is from Brandon Hanold's notes.

2 Method

We measure the tilt of the rotating face of the rotation stage in response to torque. The tilt and torque are perpendicular to the rotation axis.

[1] Biel, J., & Loh, E., 2002, "Test of the PRS 100 Rotation Stage," www.pa.msu.edu/~loh/SpartanIRCamera

A test jig (Biel & Loh 2002) allows measurement of the tilt and application of torque while the rotation stage is submerged in liquid nitrogen (Figure 1). Two posts, base-forcing and face-forcing, enable application of the torque. The base-forcing post is attached to the base, and the face-forcing post is attached to the rotating face of the rotation stage. Two posts, base-sensing, and face-sensing, enable sensing the tilt of the rotating face. Pins on the top of the posts allow measurement with a micrometer. The jig is made of stainless steel to minimize thermal conduction.

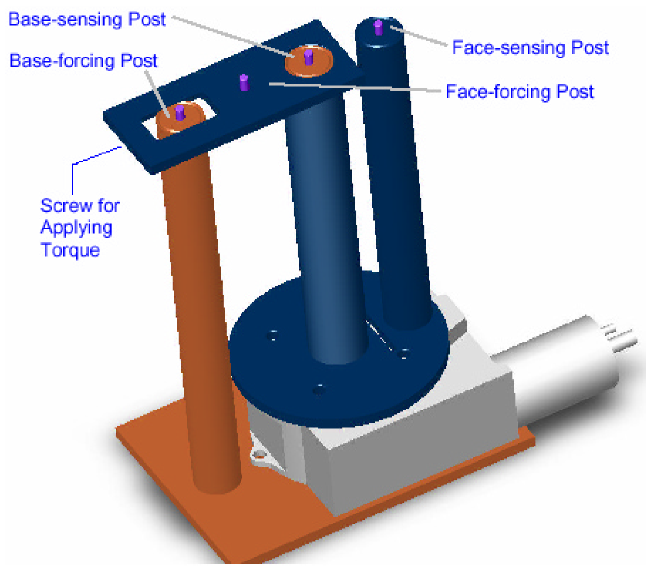

Figure 1 Test jig (picture from Biel & Loh 2002). The base (brown) is bolted to the stationary housing of the rotation stage (grey). The top (blue) is attached to the rotating face of the rotation stage. The rotation stage is submerged in liquid nitrogen, and the tops of the posts are at room temperature.

To apply a torque τ, a weight, which is tied to a string, pulls the face-forcing post to the left in Figure 1 and toward the base-forcing post.

The rotation stage has hysterisis. For the normal measurement, a large negative torque is applied first, and then the positive torque is applied slowly. A few measurements are taken with a large, initially positive torque. With the same final torque, the difference in tilt between initially negative and initially more positive torque indicates hysterisis.

A micrometer measures the distance between the sensing pins. To eliminate the torque exerted by the micrometer, we increase the separation of the jaws of the micrometer until the jaws rub slightly on both sensing pins. If the jaws push hard on the pins, the sequence of torques is reapplied to start again.

3 Results

The results at room temperature and at 77 K are shown in Figure 2. The definition of the zero angle is slightly complicated because of hysterisis. We define the zero angle so that the tilt with a large negative torque and zero final torque is equal in magnitude (and opposite in sign) to that with a large positive torque and zero final torque.

At room temperature, the tilt increases steeply with increasing torque up to 1.4 mrad. Beyond that, the system stiffens. We define the tilt at which the system stiffens to be α_0.

The hysterisis indicates friction. The work done by friction in one cycle is the area between the points taken with a large, negative, initial torque and those taken with a large, positive, initial torque. The work done by friction is 1 J at 292K and 0.5 J at 77K.

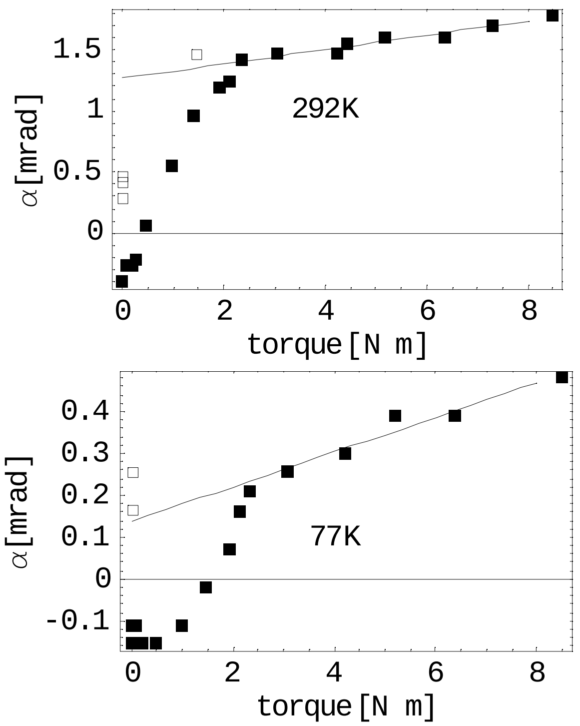

Figure 2 Tilt *vs.* torque at 292 K (top) and at 77 K (bottom). For the closed boxes, a large negative torque was applied first. For the open boxes, a large positive torque was applied first.

Our interpretation is that the bearings of the rotation stage are not engaged for $\alpha<\alpha_0$. If the bearings in the rotation stage are engaged, then $\tau = \kappa\, \alpha$, where κ is the response of rotation stage to torque. At room temperature, the response at $\alpha<\alpha_0$ is approximately linear, and we define a response κ_0 for that region.

The peak-to-peak looseness $2\alpha_0$ and response κ for SN02040-075 are summarized in Table 1.

Rotation stage SN02040-075 does not meet the requirement for the maximum tilt of 12 μrads for the f/12 channel at 77 K. The looseness is 0.4 mrad, whereas it was zero for the prototype PRS110 that we measured in 2002. The response to torque of the prototype is 6 times stiffer than SN02040-075 at 77 K and 30 times stiffer at 292 K.

Table 1 Parameters for rotation stage 02040-075

Parameter	292 K	77 K
$2\alpha_0$ [mrad]	2.8	0.4
κ_0 [μrad/N/m]	900	
κ [μrad/N/m]	60	40

4 Appendix

Water can damage the bearings and lubricant of the rotation stages. The appendix describes the procedure for measuring at 77 K without damaging condensation. The test is done in a picnic cooler (Figure 3a). The interior is dried by cooling a suspended, empty drink can with liquid nitrogen, before liquid nitrogen is added (Figure 3b). During the test, aluminum foil covers the cooler with the sensing pins exposed (Figure 3c). When the test is done, the rotation stage is placed in vacuum so that the small amount of ice on the surface of the rotation stage sublimates rather than melts.

4.1 General Procedures

4.1.1 Setup

- Bolt rotation stage into the test jig (Figure 1).
- Place the test jig with rotation stage into 1' x 2' cooler (Figure 3a).
- Prevent tipping of the test jig
    - Tape a rod to the top of the cooler (Figure 3a) to limit the movement of the base-forcing post.
    - Place blocks on the bottom of the cooler (Figure 3a). One side touches the side of the cooler while the other touches the bottom of the test jig.
- Setup the pulley system.
    - Tie a string to the test jig arm, and center the pulley.

4.1.2 Calibrating the pulley

Friction reduces the torque by 1.5% when the torque is added slowly. Friction augments the torque by 1.5% when the torque is removed slowly. The following describes the measurement.

- Move the string from the test jig and hook it to a force meter, which is placed near the test jig arm.
- Zero the force meter.
- Hang a mass on the string and slowly release the mass. This is called "gradual application" of the torque. Measure the force applied to the force meter.
- Remove the mass, and zero the force.
- Hang a mass on the string. After the mass is released, pull down on it then release the mass. This is called the "pull down application" of the torque. Measure the force applied to the meter.

4.1.3 Measuring the separation between the sensing pins

Since 0.8 N is required to move the micrometer jaws, this procedure measures the separation eliminating this force.

- While holding the micrometer over the tilt-sensing pins, separate the jaws so that they nearly touch the pins. The micrometer must be kept level and aligned with the test jig arm to 1/60 rad in order to keep the error in distance to less than 40mm(1-cos 1/60)=0.006mm.
- Measuring Response Gently insert the jaws between the tilt-sensing pins. If the jaws do not rub on both pins, increase the spacing of the jaws. If the jaws do rub on both the pins, decrease the spacing of the jaws. Continue until the change on the micrometer is less than the quantum, 0.01 mm.

Figure 3 Clockwise from top left: (a) Rotation stage and jig inside the cooler. The bar and blocks prevent the jig from tipping. (b) Cooler covered with foil. The large hole on the left is for the drying can, and the small hole is for the thermometer and for filling the cooler. (c) Setup ready for filling the drying can. A loose piece of foil covers the tilt-sensing post pins. (d) Close-up view of the drying can. (e) Pulley and weights for applying torque. (f) Close-up view of the tilt-sensing post pins.

4.1.4 Starting with Negative Torque

- Apply a large negative torque and then slowing hang the weight on the string. Then measure the separation between the sensing pins.

4.1.5 Measuring Response Starting with Positive Torque

- Pull down on the string and then slowing release the weight on the string. Then measure the separation between the sensing pins.

4.2 Procedure for Measurements at 77 K

4.2.1 Setup

- Set up the vacuum pump. Ensure that the bottom portion of the bell jar enclosure has been cleaned in the area where the rotation stage will be placed.
- Place test jig with rotation stage into cooler as in §4.1.1.
- Set up the top foil cover
  - Secure top foil cover over the sides of the cooler.
  - Form a large dimple in the far right corner of the foil cover (Figure 3b).
  - Verify that the sensing pins are sticking out of the cover (Figure 3f).
  - Using a thermometer, punch a hole in the bottom of the large dimple.
- Tape the thermometer securely in place.
- Position the drying can for removing moisture.
  - Hook the drying can on a hanging scale attached to a ring stand.
  - Lower the drying can through the large hole in the front left corner of the foil cover (Figure 3c and 3d).
  - Install the aluminum foil funnel in the top of the can, ensuring that the funnel is inserted to a sufficient depth to stabilize the funnel.

4.2.2 Removing Moisture from the Cooler

- Fill the drying can with liquid nitrogen. The can is full at 3 N.
- Continue refilling the can until the temperature within the cooler drops to –10 C, taking care not to disturb the can and thereby knock ice off the can. This should take 30-45 minutes.
- Remove the thermometer.
- Pour a small amount of liquid nitrogen in the large dimple to continue cooling while the can is removed.
- When this liquid nitrogen is all in the cooler, replace the thermometer. This will allow the temperature to be further monitored while the can is removed.
- Remove the can.
  - Slide the hanging scale off from the ring stand arm and rotate the arm so it is out of the way.
  - Carefully remove the hanging scale and can from the cooler. Do not bump the side of the cooler or touch the edges of the large hole to prevent ice from falling back into the cooler.
- Cover the large hole with foil

  - Tape down one side only to allow viewing of the rotation stage during the cooling process.
- Remove thermometer.

4.2.3 Fill Cooler with Nitrogen

- Slowly pour liquid nitrogen into the large dimple. Do not overfill the dimple.
  - Check the rotation stage for signs of ice formation while the liquid nitrogen is being added to the cooler.
  - Stop filling the cooler when the liquid nitrogen level covers the rotation stage.

4.2.4 Measuring the Response to Torque

- Scrape off ice on the sensing pins before each measurement.
- Between measurements, cover the area of the Test Jig top with a loose piece of foil to minimize the exposure to moist air.
- Measure the separation between the sensing pins with varying amounts of torque using the same procedure as that for room temperature.
- Replace the loose piece of foil for after each measurement

4.2.5 Disassembly

The goal is to eliminate water on the rotation stage. We minimize ice formation on the rotation stage by minimizing exposure to wet air. We pump the rotation stage until it warms so that ice sublimates rather than melt.

- Transporting the cooler to the vacuum pump
  - Ensure that all holes in the foil cover are sealed.
  - Clear the path to the vacuum pump, and carry the cooler to vacuum pump.
- Connect oil-free vacuum pump to bell jar enclosure.
- Remove bell jar from the bottom portion of the enclosure.
- Transfer the rotation stage to the bell jar enclosure. Gloves are required for these steps.
  - Remove the foil cover from the cooler.
  - Quickly unbolt the rotation stage from the test jig while both are still within the cooler. Do not touch any of the contents of the cooler with bare skin. The pieces of the jig and the bolts can be left in the cooler to save time.
  - Place the rotation stage on the base of the bell jar.
- Replace the bell jar. Twist the ball jar to seat it.
- Place the safety shield over the bell jar.
- Turn on the vacuum pump. Check the vacuum grease to ensure that no channels developed. Let the rotation stage warm up overnight.