Visit by Thiokol and visit to EOS and SMT

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1. Introduction

CFRP dish and encoder systems are important issues to the Millimeter Array antenna design. Recently, Thiokol was contacted for the CFRP cone study. EOS was contacted to investigate a new Heidenhain tape encoder system used on larger diameter structure rings. We also revisited the SMT to look at its CFRP backup structure and the center CFRP cylinder along with the encoding systems and their performance.

2. Thiokol's Tucson Visit

On March 20, 1996, we had an interesting meeting with visitors from Thiokol Corporation. The three visitors were manager Ivan Swenson, Principal Engineer, Kathryn F. Miks and CFRP Engineer Edward Wolcott. The attendees from NRAO are Peter Napier, John Payne, Bob Martin(invited from SMT), Jeff Kingsley and Jingquan Cheng.

Thiokol Corporation is a defense rocket firm. The main carbon fiber composite facility of the firm is for some high stiffness-to-weight ratio parts of ICBMs or other rockets. These parts include rocket motor cases, launch tubes and nozzle exit cones. They also produce other CFRP aerospace structures and CFRP natural gas storage tanks. The Thiokol Corperation has been producing CFRP parts for over 35 years.. Thiokol now has the capabilities in the following composite fields These are design, analysis, material development, process development, tooling design, tooling fabrication and verification testing. Thiokol's CFRP facilities had been over-expanded by the old space station project. The downgrade of the space station project has made most of their facilities idle for years. Therefore, they are now actively exploring new CFRP fields outside of the defence industry.

The meeting with Thiokol was mainly concerned with the central conical cone design and manufacture for the MMA. The MMA antennas have a tight thermal requirement, which drives us to adapt the new CFRP material for their backup structure. Among the antenna's backup structure, the central conical cone, which is 122 inches in diameter at one end and 80 inches in length, is the most difficult CFRP part. During the three-hour meeting engineers from Thiokol explained the design details of the MMA antenna cone, the predicted thermal and structural performance and the strategy in reducing the thermal coefficient in all the directions. The industrial study shows the cone winding angle must be ò 15 degrees to maintain fiber contact with the cone surface and the CTE control requires a lower winding angle of ~ 5 degrees. The process of lower winding angle is not stable in manufacture. Therefore they suggested a back-to-back pair cone winding approach with a winding angle of 15 degrees and using partial helical layers by stripping back unneeded material. The antenna cone has a similar size to the nozzle exit cones they have produced. Therefore, they have all the experience needed in the design, tooling and testing. The presentation of the cone design study shows that the company is quality assured and technically sound in the CFRP field.

Thiokol also has an in-house TCR prepreg and tube manufacture facility. The tube cost could be lower since prepreg is prepared inside. Therefore, they also hope to be involved in tube manufacture for the antenna backup structure. The antenna backup structure tubes have two groups: 1) lower modulus for the backing structure, and 2) higher modulus for the secondary mirror support. The expected modulus for the backup structure tube is 16 msi and for the feedleg is 25 msi. Both groups require a lower CTE in their axial direction. NRAO will provide a detailed list of the backup structure tubes for Thiokol. Thiokol will then perform a design and cost study.

For the backup structure cones of 40 MMA antennas, Thiokol provided a detailed cost breakdown. A big NRAO concern is the phase one cost (the cost for the first CFRP conical cone), which is a significant part of the total cost.

3. EOS Technology, Inc. Visit

On March 21, 1996, Jeff Kingsley and Jingquan Cheng paid a visit to the EOS Technology, Inc. in Tucson. EOS is mainly an optical telescope firm and is an abbreviation for Electronic Optical System. The main activity of the firm now is building six 0.8 m diameter Japanese optical telescopes. Mr. John Little (624-6399) is the person we contacted and Mr. Larry Random is the director of the company.

The purpose of this visit was to see the installation of the optical tape encoder used at the azimuth axis for these telescopes. The optical tape encoder is made by Heidenhain in Germany at a cost of $2.37/mm. The tape has an accuracy of 3æm with the signal period of 100æm when it is used as a linear encoder. Bonding the tape to the ring is done with epoxy. The tape is bonded to the inner surface of the ring. The tape, when it is bent, has a tendency to spring back. This produces a uniform pressure over the bonding surface. This is the main reason why an inner surface of the ring is used for the encoder. The critical problem in the tape bonding is that the length of the tape and the diameter of the ring have to be exact to microns. Another problem is that the ring surface needs a shoulder to stop the tape during bonding. In the first telescope we saw at EOS the tape joint was not well aligned since the ring had no shoulder to stop the tape in the axial direction. The other two encoder tapes were perfectly aligned in position. The ring surface of the EOS telescope is machined when the azimuth bearing is mounted on structure. The encoder read heads cost $1,093 each and are small in size at 40 mm x 15 mm x 20 mm. The gap between the read head and the tape is 800 um. The tolerance is 150 um in both directions. Two read heads will be used for each of the encoder systems. Each encoder has an external interpolation and digitizing box EXE660 that costs $700 each. With this setup, the accuracy of the encoder should be 0.003/800=0.77 arcsec with two read heads (a calibration table may be needed.). With only one read header the bearing runout will be the dominant error source. The target resolution of the EOS encoder is 0.03 arcsec, and its expected accuracy is under 1 arcsec. The tape allows some contamination during operation. Heidenhain also provides a similiar tape of 5 um linear accuracy. Unfortunately, EOS has no test data for resolution and accuracy of their encoder system yet.

The EOS telescopes are for laser guidance. Their azimuth acceleration is high: 5 degrees/sec-sec. To reduce the moment of inertia of the structure, most of the construction is of aluminum plates or tubes, even for the yoke and the tube structure. There are three invar rods between the primary and secondary mirrors to keep the separation constant. The azimuth encoder ring is a thin steel structure; its top is covered by a steel plate to form a welded element. This steel part is then fixed to the yoke by epoxy and screws. The thickness of the encoder ring is about 10-12 mm. The ring also serves as a main driving wheel of the azimuth axis. Two friction drive wheels apply force on its outer surface. The EOS encoding system appeared to be well implemented, but we are still interested in the final system performance results.

4. SMT Revisited

On March 28, 1996, Antonio Perfetto, Jeff Kingsley and Jingquan Cheng visited the Submillimeter Telescope on Mt. Graham. Some of us had visited SMT 2 years ago. The purpose of this visit was to review the SMT CFRP backing structure, tube joints, panel supporters, cone structure and its incremental encoder system.

The telescope is now in its operational stage. Receivers are placed at two Nasmyth foci. We noticed that the backing structure is covered with protective cloths to avoid UV radiation. The feedlegs are CFRP material and painted to protect them from UV. The tubes of the backing structure are in perfect shape, just as when we visited two years ago, with no apparent surface difference. The CFRP tubes, made by the Swiss company Cellpac (CTE=0.65 x 10^-6/K, Baars and Martin, 1990 ESA SP-314) are connected with Invar joints by small M6 screws. The invar joints used are small, about 80 mm in diameter. However, when two tubes join at a small angle, they have to be connected via another tube-like subjoint. There is a long narrow slot, 8 mm x 50 mm, for the access of the Allen key fastener wrench in each end of all CFRP tubes. Tightening the connecting screw from the narrow slot is a special job requiring hours of practice. The central cylinder of the dish has a diameter of 860 mm and a height of 1,120 mm. The cylinder is of CFRP with a thickness of 6.5 mm. The top and bottom of the cylinder are invar rings glued by epoxy. These Invar rings may be very expensive too. The panels of the SMT are a CFRP honeycomb structure. The panel adjusters are differential screws with a pitch of 0.4 mm per turn. The adjuster has a very slim 3 mm diameter neck to reduce the bending force on the panel surface. Four adjusters are used for each panel except the outer ring. In the outer ring the panel has an additional support at the center of the panel. The surface RMS error now is 20 um. In detail, the first ring is 10 um, the second ring is 15 um and the third ring is 20 um. It is expected that the dish could be adjusted to 15 um RMS. The panel adjustment is done from the back of the dish. Climbing on the backing structure results in no residual change in surface RMS error.

The encoder used at the SMT is an incremental one, with a single point mark. The encoder is formed by a disk and a scan head. The disk has its inner diameter of 150 mm and outer diameter of 260 mm. The disk and scan head are in a holder with bearings. The inner diameter of the encoder system is 120 mm. The encoder works well. Currently the dead pointing of the telscope is 3 arcsec RMS, relative pointing within hours is 1-2 arcsec. Tracking stability is better than 1 arcsec and the pointing pattern is extremely repeatable. The telescope also points very well when the surface is exposed partly or wholly to the sunlight while tracking sources. The incremental encoding system at the SMT is a proven accurate and reliable system. Normal operation only requires the telescope to reference to an absolute mark once a day. There is never a problem of losing track.

After the SMT visit, Bob Martin had a talk with Jeff and Jingquan. We reviewed the telescope blueprints to examine further the connection of the backup structure and center ring. While reviewing we discovered a special azimuth bearing, a three-row roller bearing. This bearing is capable of transmitting very high loading. It has very high bending stiffness while keeping very accurate radial runout. This bearing is ideal for the slant axis telescope bearings or the conventional telescope azimuth bearing.

5. Summary

All three contacts have increased our understanding of elements and options of the CFRP and encoders in the design of the MMA antennas. The visit by Thiokol to Tucson has identified the cost and construction options of the center cone and backup structure tubes. EOS has offered valuable design ideas and will test the new Heidenhain ring encoder system for accuracy and reliability. The SMT has demonstrated how well CFRP and incremental encoders are being used under similar specifications to the MMA antennas.

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