

CFRP composite optical telescope assembly for the 1m ULTRA project

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ABSTRACT

Carbon Fiber Reinforced Plastic (CFRP) technology is being used to produce an Optical Tube Assembly (OTA) and mirrors for an astronomical telescope facility. This paper addresses the design and fabrication of the OTA for the ULTRA project 1 m telescope. Mirror development is discussed in another paper in this conference.

Keywords: CFRP, Optical telescope, ULTRA

1. INTRODUCTION

The focus of the ULTRA Project is to develop and test Ultra-Lightweight Technology for Research applications in Astronomy. The ULTRA project is a collaborative effort involving the private firm Composite Mirror Applications, Inc (CMA) and 3 universities: University of Kansas, San Diego State University, and Dartmouth College. Funding for ULTRA is predominately from a NSF three year MRI program grant to CMA and KU with additional support from CMA, KU and SDSU. The goal of the ULTRA program is to demonstrate that a viable alternative exists to traditional glass mirror and steel telescope technology by designing, fabricating and testing a research telescope constructed from carbon fiber reinforced plastic (CFRP) materials. In particular, a 1m diameter, Cassegrain telescope optics set and optical tube assembly (OTA) are being designed and fabricated by CMA. The completed telescope will be deployed at SDSU's Mt Laguna Observatory in a refurbished structure (new dome and mount provided via KU and SDSU). We expect that a successful completion and testing of this project will lead to future use of CFRP technology in larger telescopes and segmented telescopes. This paper describes the OTA (optical tube assembly) that has been developed for the ULTRA project. The mirror technology is described in another paper in this conference. A poster describes the ULTRA project overview in more detail.

2. MATERIALS

CFRP (carbon fiber reinforced plastic) is an attractive material for fabrication of optical systems. As detailed in another paper, the mirrors in this optical system are fabricated by replication techniques. Layers of unidirectional, CFRP prepreg are layered over a mandrel that has the complementary shape of the desired mirror. After curing of the lay-up structure and removal from the mandrel, the mirror surface is aluminized in the same manner as conventional glass mirrors. The mandrel can be reused to generate multiple copies of the same mirror shape.

We have also chosen to use CFRP extensively for the OTA structure. CFRP has a number of material properties that make it attractive for structures.

- The stiffness-to-weight ratio of CFRP is about 5 times greater than steel. The Young's modulus is similar to steel while the density of CFRP is much lower than steel. Thus, stiff, lightweight structures can be fabricated with CFRP.
- The coefficient of thermal expansion for CFRP is very low at 1-2 ppm. This is roughly 20 times lower than for aluminum. Structures fabricated with CFRP are dimensionally stable with respect to thermal changes.

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- The thermal conductivity of CFRP is similar to steel. This property, coupled with the lower mass of a CFRP structure, results in rapid thermalization. Thermal gradients are minimized in CFRP structures.
- CFRP structural elements are fabricated as a lay-up of unidirectional prepreg fiber. The structural elements can be optimized to take advantage of the CFRP non-isotropic properties or can be tailored to yield quasi-isotropic behavior.

In designing the OTA, we have chosen some key fabrication techniques with CFRP that take advantage of the mechanical properties. One example of this is the use of tubes that are loaded only in an axial direction. We design these tubes with most of the prepreg layers running the fiber in the axial direction. This maximizes the stiffness in the direction that the tube is loaded, resulting in a stiff, lightweight design element.

A second example is the extensive use of sandwich panels in our design. These sandwich panels use CFRP facesheets and aluminum honeycomb core. The in-plane thermal and mechanical properties are dominated by the CFRP material properties. And, of course, the panel stiffness is a strong function of the thickness. The aluminum dominates the thermal properties only in the thickness direction of the panel. By appropriate orientation of the panel in the overall design, the CFRP properties can be used to advantage.

There are circumstances when CFRP is difficult to use for structural elements. We use steel (stainless when possible) for fasteners. It would be extremely expensive to custom fabricate fastener hardware from CFRP. For small, intricate interfacing parts which require extensive machining we have used aluminum or stainless.

3. OTA DESIGN

3.1. General OTA specifications

The optics for this OTA is a classical Cassegrain set. The primary mirror is a 1 m diameter $f/3$ parabola. The final f ratio is 7.6 with the focus located 530 mm behind the primary vertex. The secondary mirror is 343 mm in diameter. The OTA must support an instrument package that will be located behind the OTA.

3.2. OTA design features

The optics for this OTA are much lighter than similar mirrors made in the traditional manner from glass. In this case, the primary mirror will be only about 20-25 Kg and the secondary mirror will be about 5 Kg. The instrumentation package, however, will be the same as one used on a traditional glass and steel telescope. The ULTRA instrumentation package is expected to be up to 50 Kg. These requirements lead to an OTA design that keeps the weight (and required stiffness) near the declination axis as much as possible. The top end, or head ring and spider assembly, can be kept very lightweight. Figure 1 illustrates the OTA design for ULTRA.

The OTA will be attached to an equatorial fork mount being manufactured by ACE (Astronomical Consultants & Equipment) of Tucson, AZ. The OTA will attach to the mount via steel declination axle stubs in the 2 cups shown on the side of the OTA dec-box assembly. The OTA dec-box forms the base of the assembly. This structure is 12 sided and is formed from 40mm thick CFRP-aluminum core sandwich panels. The top, bottom and ribs of the dec-box are also sandwich panels. The assembly is reinforced with brackets and joining plate custom fabricated from CFRP. Thermal mismatch between the steel mount and the OTA is accommodated by the pre-loaded, floating bearing assembly on one side of the mount's declination axis.

The telescope primary mirror is mounted to the inside base of the dec-box assembly. Since the thermal properties of the OTA are virtually the same as the CFRP primary mirror, the mounting can be a relatively simple design. The instrumentation package is mounted to blades at the outside bottom of the dec-box assembly. This transfers the load of the instrumentation package directly to the edge of the dec-box and through to the declination axis without distorting the mounting plane of the primary mirror.

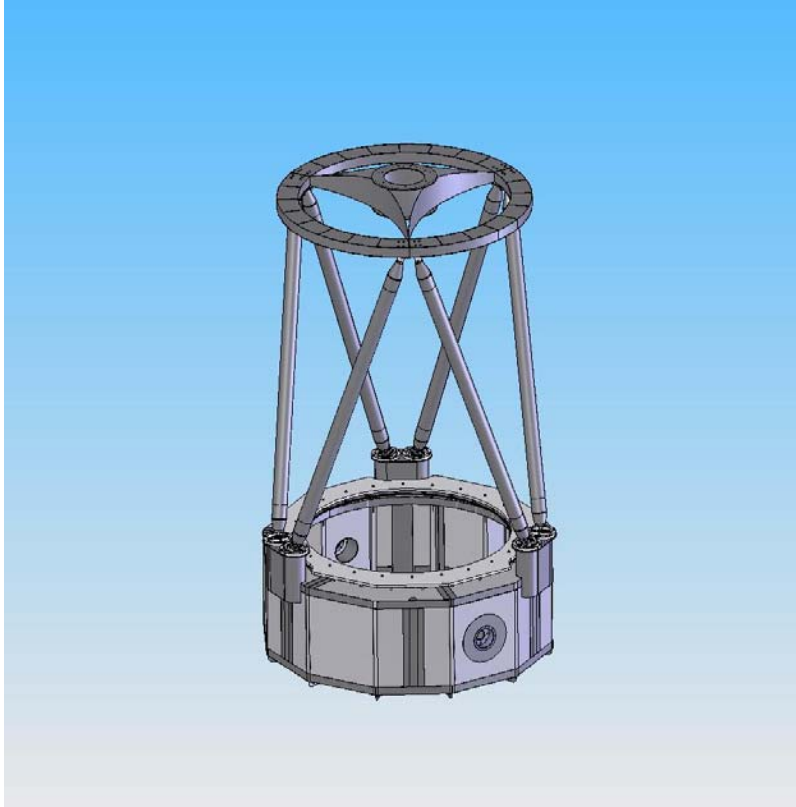


Figure 1: The ULTRA OTA design model.

The top of the dec-box is closed out with a 24 blade iris assembly. This provides protection of the primary mirror when the telescope is stowed. In addition, it allows the primary to be stopped down in aperture for optics and engineering testing.

The head ring is fabricated from CFRP as a thin wall, square cross section tube. Bulkhead plate supports are provided for reinforcement. The spider blades and secondary mirror mount area are CFRP plate elements (and tubes). The entire head ring, spider, and secondary mount assembly is less than 4 Kg in mass. The secondary mirror is mounted to the secondary support with a simple 3-point mount. Again, the thermal properties of the mounting plane are the same as the secondary mirror itself.

3.3. Hexapod top end and secondary control

Six strut tubes are used to connect the top end (head ring, spider vane and secondary support) to the dec-box of the OTA. These six struts are adjustable in length and form a hexapod control system for the top end. Thus, there are six degrees of freedom for the adjustment between the primary mirror and the secondary mirror. Tip, tilt, x, y, and z alignment of the optics are all done with the hexapod struts.

The strut tubes are mounted to the head ring and dec-box base using Gimbal type mounts. Flex pivots are used for the bearing elements to provide an attachment that is free of backlash. With this mounting arrangement, the static loading of the strut tubes is axial only. Conical end fittings (of CFRP) are used between the tubes and the mountings. The CFRP lay-up of the tubes is optimized for stiffness in the axial direction.

The mounting to the strut tube assembly to the head ring is a fixed, 2 axis arrangement as shown in figure 2. The bottom end of the strut, at the dec-box end, is mounted via a precision ball screw to the dec-box Gimbal mount. The bearings on this Gimbal mount are also flex pivots (without backlash). The ball screw assembly is used to adjust the length of the strut tube. The preload of the ball screw nut eliminates backlash in this adjustment. The ball screw is driven (and controlled) by Nanomotion piezo motors which drive against a ceramic ring. Figure 3 illustrates the arrangement. A precision length encoder is used for feedback position with the drive system for each strut. All of the motors, ball screw and drive are kept at the lower end of the strut tube so that the weight of the OTA top end assembly is minimized.

The low mass of the top end assembly and optics allows us to use this unique piezo drive for the strut tube adjustment. These motors will hold the position in place when not powered. The motors only need to be powered when adjustments are actually being made. This minimizes heat dissipation in the area near the OTA and optics.

Key components of the OTA design have been analyzed using a commercial finite element analysis (FEA) software package (COSMOS). These analyses were used to verify the design direction.



Figure 2: Strut tube top mounting to head ring with flex pivot Gimbal.



Figure 3: Lower strut mount. Drive motor located under mount

4. STATUS AND SCHEDULE

Construction of the OTA and optics is almost complete. The OTA and optics package will be assembled with the steel mount in June 2006 for initial testing. Figures 4 and 5 show the OTA assembly near completion in the CMA shop. The final mass of the OTA is less than 65 Kg (without optics).



Figure 4: OTA near completion at CMA



Figure 5. OTA near completion at CMA.

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