Evaluating the Design of the Tertiary System

Jerry Nelson

2014 January 20, rev2

1 Introduction

There are several parts of the tertiary system that should be evaluated

A The mirror itself –mainly the polishing

B The performance of the mirror support system under the varying effects of gravity (the axial and lateral support systems)

C The repeatability of the deployment-retraction system

D The performance of the system that carries the mirror support system) under the varying effects of gravity

E The blockage of the cassegrain focus

F The repeatability and speed of the bearing system

Since the mirror is inclined at 45 deg, the tolerances are not symmetric on the mirror surface. In the surface of the mirror we use the major axis to define the x-axis and use the minor axis to define the y-axis. Rotations of the mirror about the x-axis by θ_y will move the star image by $6.5/150*\theta_y$. Rotations about the y-axis will move the star image by $2*6.5/150*\theta_x$. The requirements therefore need to be given for the two directions separately.

2 Polishing

The mirror should be polished smooth and flat. The projected size of a single star on the tertiary is 0.476m. Surface slope errors θ_x should be no more than 8.4e-7 radians rms (0.015 arcsec rms on the sky) in any 0.476m patch and θ_y slope errors should be no more than 1.7e-6 radians rms. This is a geometric optics approximation. It is worth noting that the diffraction limit of the telescope will give an rms image size ~ λ/D which for λ=500nm is 0.010 arcsec, so the requirement for the tertiary is close to the diffraction limit, where surface error is an appropriate error metric. Another way to express the desired surface quality is to say that the rms surface error over any 0.476m patch should be no more than 50 nm rms (a Strehl of 0.67 at 1 μm). The slopes and rms surface errors are connected via the spatial frequency of the errors.

If we pick focus for example, the rms slope is

$$\sigma_{xslope} = 2\sqrt{3}\,\frac{rms\ \text{surface}}{a}$$

which gives for $\sigma_{x\ slope}$ =8.4e-7 radians and a=0.238m, an rms surface error of 57.7 nm.

If we pick spherical aberration as another example, the rms slope is

$$\sigma_{xslope} = 3\sqrt{5}\,\frac{rms\ \text{surface}}{a}$$

which gives for $\sigma_{x\ slope}$ =8.4e-7 radians and a=0.238m, an rms surface error of 29.8 nm.

Writing a proper spec for the polishing is a complex issue.

The surface roughness should be no more than about 2nm surface rms (tip-tilt removed) over any 2 mm patch.

3 Mirror support system

We assume the mirror is polished perfectly in the absence of gravity. We want the gravity induced surface slopes to be no more than 5e-7 radians rms so the polishing errors will dominate. The present design of the axial system (6 point support) has rms slopes under full axial gravity that are a bit less than 3e-7 radians in the x direction, and<3.2e-7 in the y direction. The lateral support gives an rms of tbd radians under full gravity along the minor axis and tbd radians under full gravity along the major axis.

For a single on-axis star the full axial support gives an rms slope of 2.6e-7 radians in x and 2.9e-7 radians in y and an rms surface error of 22 nm. The lateral support gives tbd

4 Repeatability of the Kinematic System

Assuming a kinematic system, the only important source of non-repeatability is friction. We want the system to repeat to 1 arcsec or better on the sky, so tilts of the tertiary should be under 1.12e-4 radians about the local x-axis and about the local y-axis to better than 5.6e-5 rad. If we assume the kinematic mounts are at a radius of 0.6m then we need axial repeatability of $\delta = 0.6\phi/\sqrt{3}$ or 19μm or better. The main concern is the misalignment (tilt) of the v-grooves relative to the plane defined by the bipod legs. We will require that

$$\mu \frac{Mg}{3\sqrt{2}}\frac{\varepsilon}{k} \le \delta$$

where ε is the misalignment of the v-groove relative to the normal defined by the bipod legs

k is the stiffness of the bipod legs to a force normal to the plane defined by the bipod legs

μ is the coefficient of friction

M is the mass being supported by the kinematic system δ is the needed axial repeatability of each support.

For μ=0.2, M=100kg, ε=0.01 radians, δ=19μm we find that we need k≥2.43e4N/m. As discussed in the note "Kinematic Mount for Deployable Tertiary (Nelson, 2014) the out-of-plane deflection for a single strut is

$$\delta = \frac{FL^3}{3EI}$$

or

$$k = \frac{3EI}{L^3}$$

For hollow cylindrical tubes,

$$I = \frac{\pi}{4}(r_o^4 - r_i^4) = \frac{\pi}{4}(r_o^2 - r_i^2)(r_o^2 + r_i^2) = \frac{A}{4}(r_o^2 + r_i^2)$$

we find for A=2e-4m, r_o=0.0125m, r_i=0.000962m, L=0.762m, I_{strut}=1.244e-8 m^4 so the stiffness of the bipod (2 struts) is k=3.37e4N/m large enough to meet our requirements.

5 Gravity induced Rotations of the Mirror Support System

The structure that carries the load from the mirror support system to earth will deform as a function of elevation angle, and which focus is being used. We want any induced tilt of the mirror to be small compared to other telescope based errors, which are about 15 arcsec. If we let the resulting image motion on the sky to be no more than 5 arcsec, the mirror system can rotate no more than 2.8e-4 radians over 90 deg change in elevation.

6 Blockage of the Cassegrain Focus

At present the field of view is limited by the tertiary tower and vignetting by the secondary. If we can keep our blockage to that of the tertiary bearing that is acceptable. It is probably acceptable also if at a minimum the LRIS and MOBIE fields of view are not blocked. If the tertiary system must corotate with the cassegrain instrument that is tolerable, but clearly a complication. A desirable goal for the design is that when stowed, corotation is not needed.

7 The Bearing System

Since moving the tertiary in and out and rotating it will be done at night, speed is valuable. Making all motions in no more than 60 sec is desirable. The rotational repeatability should be no worse than 1 arcsec on the sky, or 23 arcsec rms at the bearing. The accuracy is not so important since this is largely a question of pointing offsets.