Flexure of Pisco Dichroics

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Alan Uomoto has pointed out that the shape of the partially-reflective surfaces on the dichroic elements in PISCO are as critical as any mirror in an optical system, even though these elements must allow light to pass through as well. Since the dichroics are angled with respect to the beam, the through beam will experience some aberration, which can be minimized by making the dichroic thin. This raises a concern that the dichroic elements will either distort significantly under their own weight, so as to affect the optical quality of the reflected beam, or that alternately they will need to be so thick that the quality of the through beam is affected. This memo addresses that concern.

Finite element analyses were done of thin glass cylinders similar in size to the dichroic elements needed for PISCO, in both Autodesk Inventor and SolidWorks/COSMOS. The cylinders were subjected to a one-gravity acceleration in various directions, and the displacement under their own weight was calculated. Acceleration components parallel to the flat glass surface have little effect; we will therefore consider only a one-gravity acceleration perpendicular to the flat surface. This results in the flat glass surface distorting into a segment of a weakly spherical shell. Call the deflection at the center δ. A plot of δ for various dichroic thicknesses are plotted in Figure 1.

The dichroics will be glued into a metal cell. As a worst-case, the cell will constrain the dichroic along a circular edge. Perhaps the glue will also constrain the entire cylindrical outer surface as well—if so, this reduces the displacements by a factor of about two, as shown in Figure 1.

About thirty finite element analyses were done. For the case where only a circular edge is constrained, the results are well fit by:

$$\delta \;=\; 273\,\mathrm{nm}\;\left[\frac{D}{175\,\mathrm{mm}}\right]^{3.88}\;\left[\frac{t}{5\,\mathrm{mm}}\right]^{-1.85}\;\left[\frac{\rho}{2.5\,\mathrm{g\,cm^{-3}}}\right]\;\left[\frac{E}{69\,\mathrm{GPa}}\right]^{-1}\;, \tag{1}$$

where D is the diameter of the dichroic, t is its thickness, ρ is its density, and E is its coefficient of elasticity. Poisson's ratio is taken to be 0.23 for glass.

The distorted dichroic has a radius of curvature

$$R \;=\; \frac{D^2}{8\,\delta}\,. \tag{2}$$

This value can be put into the ZEMAX model of the optics as the curvature of a dichroic mirror element. Figure 2 shows the point spread function where the dichroics are undistorted; Figure 3 shows the point spread function where the the first dichroic reflector has a radius of curvature $R = 5 \times 10^6$ mm. It is found that radii $R > 5 \times 10^6$ mm have essentially no effect on the image quality. This is the case even though the sag, δ, in the dichroic is of order a wavelength, because the PISCO optical system is not diffraction-limited. The condition that $R > 5 \times 10^6$ mm can be written as

$$t > 2.9\,\mathrm{mm}\left[\frac{D}{175\,\mathrm{mm}}\right]^{1.02}\left[\frac{\rho}{2.5\,\mathrm{g\,cm^{-3}}}\right]^{0.54}\left[\frac{E}{69\,\mathrm{GPa}}\right]^{-0.54}. \tag{3}$$

We see that this condition can be met with an typical glass filter thickness of about 5 mm. Note that ordinary optical glass, such as BK7, is slightly better in this application than fused silica—the fused silica is less dense, but its “specific coefficient of elasticity”, E/ρ, is nonetheless smaller than most optical glasses.

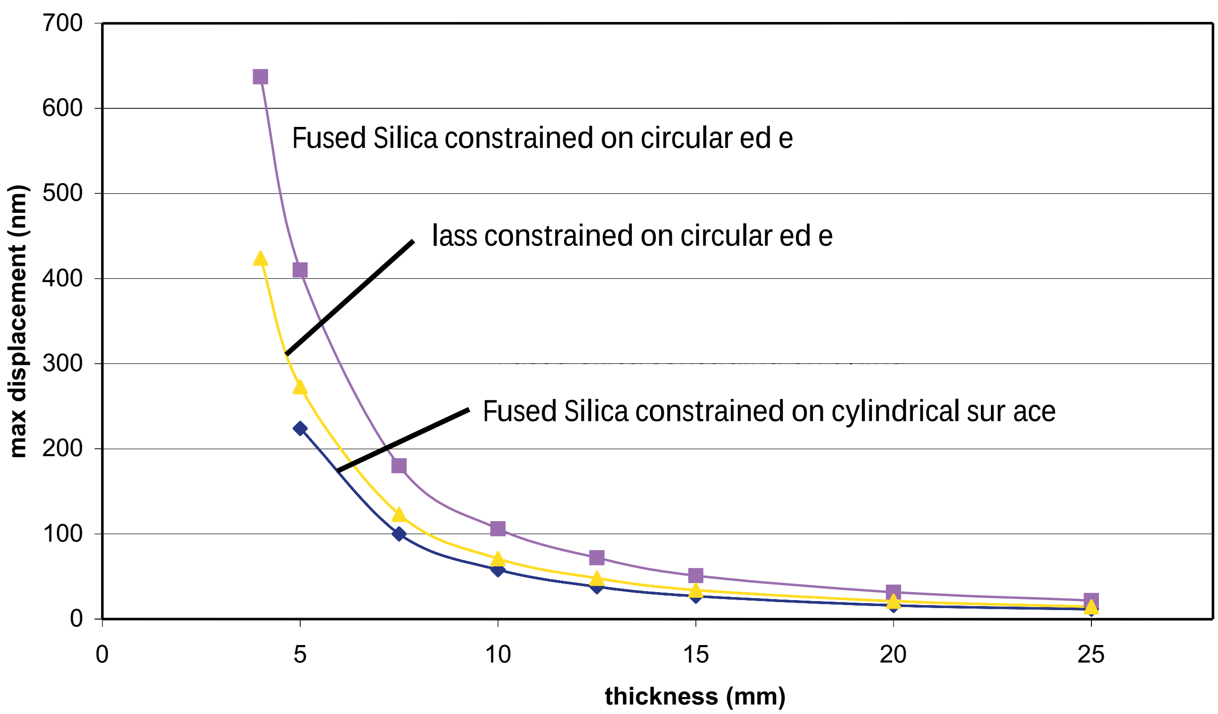

Fig. 1.— The displacement under gravity, δ, of the center of a 175 mm diameter filter, measured in nanometers, as a function of thickness, measured in millimeters.

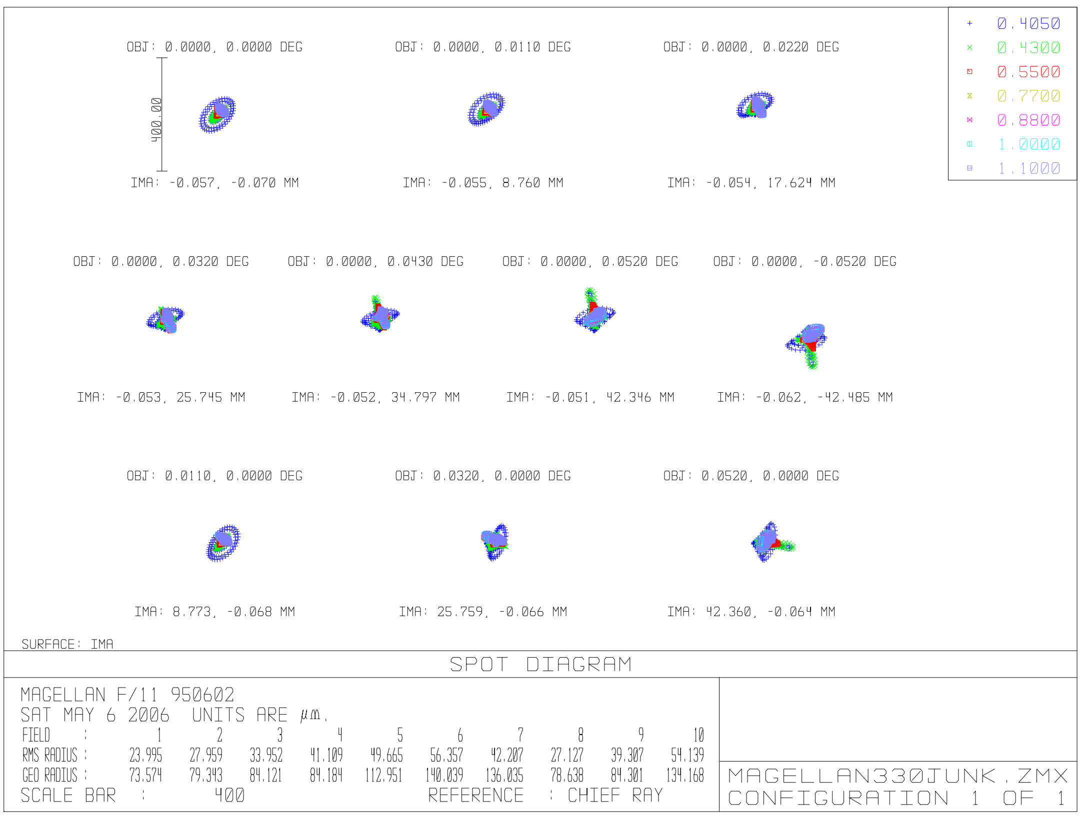

Fig. 2.— The point-spread distribution of model 330 of PISCO, where the dichroic reflectors are perfectly flat.

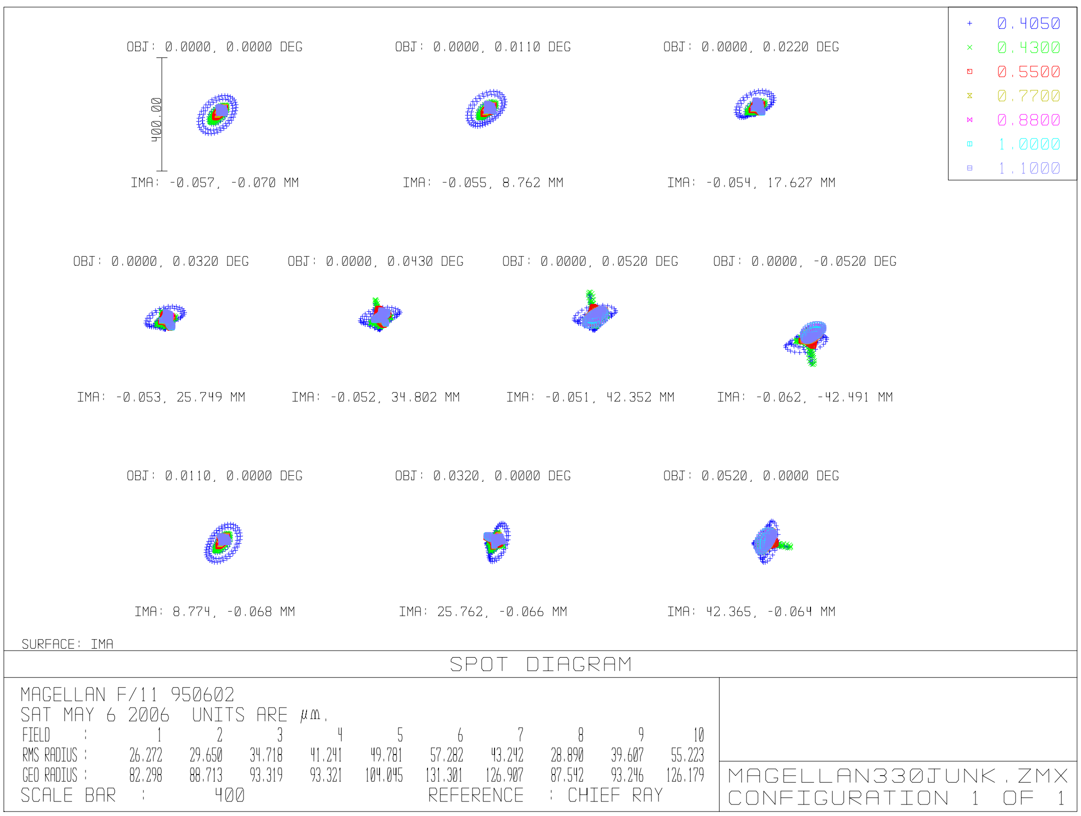

Fig. 3.— The point-spread distribution of PISCO, where the reflective surface of the first dichroic has been distorted to a radius of $R = 5 \times 10^6$ mm.