Tillinghast secondary tilts

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Sensoft analysis of TWFS images yields a prescription for adjustments of the secondary as “tilt M2 East by X′′ and North by Y′′.” I calculate the numbers of turns of 2 of the 3 bolts that tilt M2 with respect to the optical axis to yield the Sensoft prescription.

Figure 1 is a low-quality reproduction of a photograph of a full-scale drawing of the back of the plate that holds M2. The 3 adjustment bolts are labeled A-C, and N marks the north direction. Figure 2 is a copy of a cut-out diagram (reduced from full-scale) along line AA in Figure 1, showing M2 and bolt A. Figure 3 is a diagram of the plate shown in Figure 1, with labels for the 3 bolts, the cardinal directions, and 2 known angles I use in the calculations. Various axes are also shown.

The Sensoft prescription gives the rotation angles $\delta_E$ (tilt M2 East) and $\delta_N$ (tilt M2 North). These are small angles in radians, so I treat them as vectors. When a bolt is turned, M2 rotates about the axis formed by the other 2 bolts. I’ll leave bolt A fixed, as we have 2 degrees of freedom. I picked A to remain fixed, because access to B and C is easier with the telescope tilted toward the mezzanine. Turning bolt B (C) then rotates M2 about axis AC (AB). These axes are shown in Figure 3 in green and red, respectively. In matching colors, axes parallel to AC and AB (A'C' and A''B', respectively) are shown through the center of M2. These define angles $\alpha$ (NA') and $\beta$ (NA'') which relate small rotations about AB and AC to correspondingly small rotations about NS and EW:

$$\begin{align*}
\delta_E &= \delta_B \cos(\alpha) + \delta_C \cos(\beta) \\
\delta_N &= \delta_B \sin(\alpha) - \delta_C \sin(\beta)
\end{align*}$$

Figure 3 shows vectors representing $\delta_B$ (green) and $\delta_C$ (red). For small motions of the bolts, in the small-angle approximation $\delta_B$ and $\delta_C$ satisfy:

$$\delta_B = \frac{h_B}{R}, \quad \delta_C = \frac{h_C}{R}$$

where $h_B$ and $h_C$ are bolt displacements (positive away from M2) and $R$ is the distance from each bolt to its corresponding axis of rotation (e.g., B to AC), which in turn is equal to the radius of the bolt circle multiplied by 1.5, from the geometry. The signs of $\delta_B$ and $\delta_C$ are such that positive $h_B$ and $h_C$ produce CCW rotations about AC and AB, respectively. These displacements satisfy:

$$h_B = \frac{T_B}{P_{mm}}, \quad h_C = \frac{T_C}{P_{mm}}$$
where $T_B$ and $T_C$ are the numbers of CW turns of the bolts and $P_{mm}$ is the pitch of the bolts in turns per mm.

Solving eqn. 1 for $\delta_B$ and $\delta_C$ yields:

$$T_B = RP_{mm} \frac{\delta_E \sin(\beta) + \delta_N \cos(\beta)}{\sin(\alpha + \beta)}$$

$$T_C = RP_{mm} \frac{\delta_E \sin(\alpha) - \delta_N \cos(\alpha)}{\sin(\alpha + \beta)}$$

(2)

The quantities required to calculate $T_B$ and $T_C$ are:

$$\alpha = 7.55^\circ$$
$$\beta = 52.45^\circ$$
$$R = 1.5 \times 187. \ mm$$
$$P_{mm} = \frac{24 \text{ turns/inch}}{25.4 \ mm/inch}$$

The Sensoft prescription based on the best data from 23 March 2009 is:

$$\delta_N = 80.2''$$
$$\delta_E = 188.2''$$

Using the equations above and scaling the prescription from arcsec to radians, I obtained:

$$T_B = 0.294$$
$$T_C = -0.081$$

These are very small turns, so I conclude that we are reasonably close to a good collimation.

We will test TWFS further by turning bolts one at a time and acquiring images to verify that Sensoft yields the appropriate corrections.
Fig. 1.—
Fig. 2.—