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MMT Observatory

Smithsonian Institution &
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Pointing/Derotator Coalignment for Alt-Az Telescopes

G. Schmidt

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Gary D. Schmidt

Abstract

The effects of a misalignment between the telescope pointing axis and instrument derotator axis for an alt-az telescope are analyzed. For reasonable amounts of misalignment, the residual field rotation is sufficiently small that image blurring in the inner 1–2 arcminutes is negligible except for a very narrow cone surrounding the zenith, some of which is excluded from pointing due to the rapid azimuthal slew rates that are required for diurnal tracking.

Introduction

Field derotation is a necessity for today's largest telescopes, which universally employ altitude-azimuth mounts. Often called the "3rd axis" of the telescope, an instrument rotator at the Cassegrain focus of a 6-8 m class telescope must be able to suspend weights in excess of 2 tons and track accurately at continuously variable rates exceeding 1°/sec. Of course, the required derotation rate depends on position on the sky; thus there exists a tolerance on any misalignment between the telescope pointing axis (about which the field rotation is computed) and the rotator axis (about which the derotation is applied). The latter is sometimes called the "sweet spot." A telescope whose pointing axis coincides with its derotator axis will require minimum guiding corrections with changing hour angle, and if guiding is done using a single star in the field of view, the target will be maintained in the entrance aperture of the instrument even if that aperture is not centered on the derotator axis. This consideration is one of the primary reasons for collimating the optical axis of a telescope to a fundamental axis described by the instrument derotator. This memo derives the tolerance required for pointing/derotator coalignment for realistic observing conditions. Note that the use of two guide stars at opposite edges of the field – as is done with the wide-field MMT *f*/5 instruments – avoids this constraint because guiding is achieved in all 3 axes simultaneously, i.e., the derotation rate is not computed solely from the telescope pointing.

Field Rotation for Alt-Az Mounts

The parallactic angle η is the angle between an object's hour circle and its vertical circle (Figure 1). The rate of change of parallactic angle gives the field rotation rate that must be corrected by an instrument derotator. For an observer at latitude L, a star field centered at zenith distance z and azimuth A will rotate at a rate

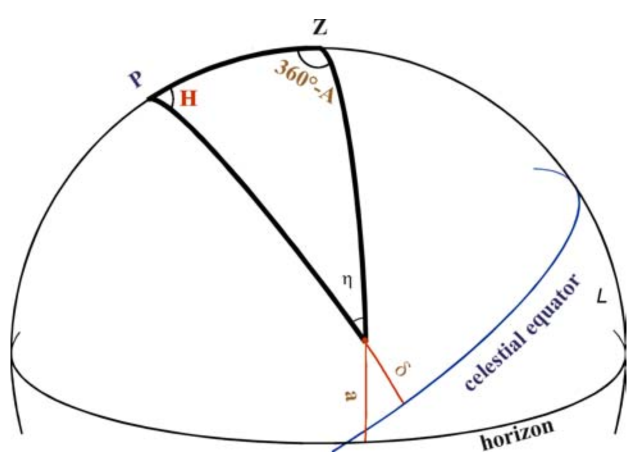

Figure 1: Definition of parallactic angle η

$$d\eta/dH = -\cos L \cos A \,\mathrm{cosec}\, z$$

(Smart 1962), where H is the hour angle. With $a = (90° - z)$ and $dH/dt = 15°/\mathrm{hr} = 0.262$ rad/hr,

$$d\eta/dt = -0.262 \cos L \cos A \sec a \;\; \mathrm{rad/hr}.$$

Figure 2 displays this function vs. azimuth for several altitude (elevation) circles as observed from a telescope at the latitude of the MMT. Note that over the majority of the sky ($a \leq 65°$), $d\eta/dt < 0.5$ rad/hr, but the quantity increases rapidly, to eventually reach ∞ for an object that tracks directly through the zenith.

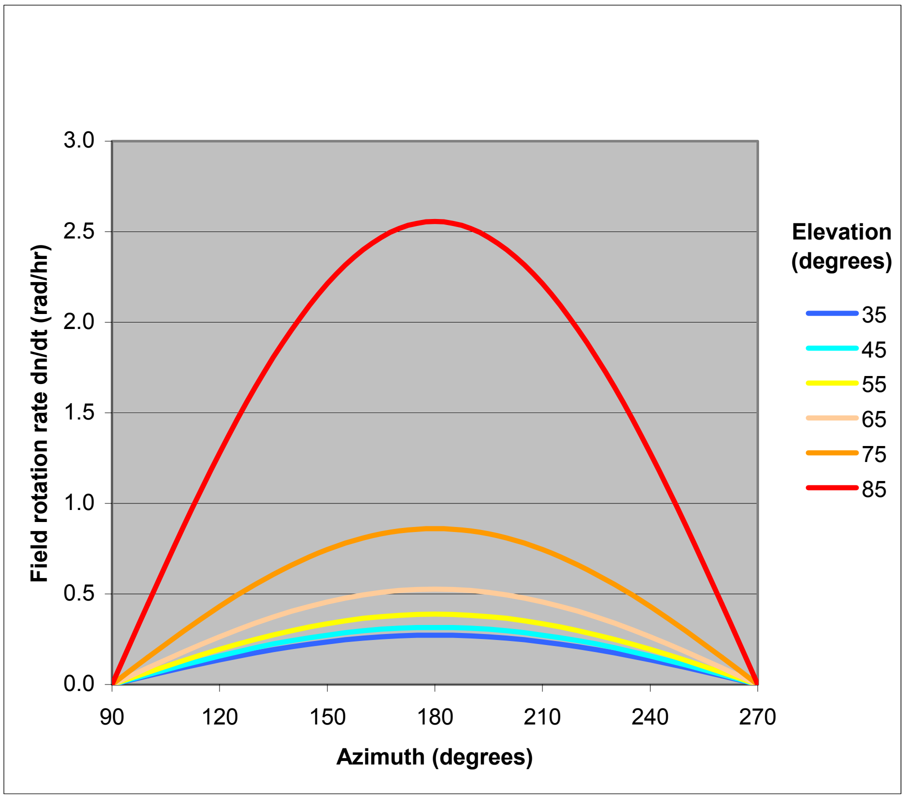

Figure 2: Field rotation rate with azimuth for a range of altitudes (elevations). Objects that pass to the north of zenith behave identically, except for a change in sign of the rotation rate. The latitude of the MMT is assumed.

Misalignment of the Pointing and Derotator Axes

Misalignment of the pointing and derotator axes results in a derotation rate that is computed for one location in the sky (the telescope pointing axis) but is applied around another (the rotator axis). The effect is residual field rotation at a rate $\Delta(d\eta/dt)$, which is simply the difference between the two rates. The derotator lags the true rotation if the rate computed for the pointing axis is smaller than that at the rotator center, and leads it if vice-versa. $\Delta(d\eta/dt)$ is shown in Figure 3 for an assumed 1 arcmin decentering (in elevation) of the two axes.

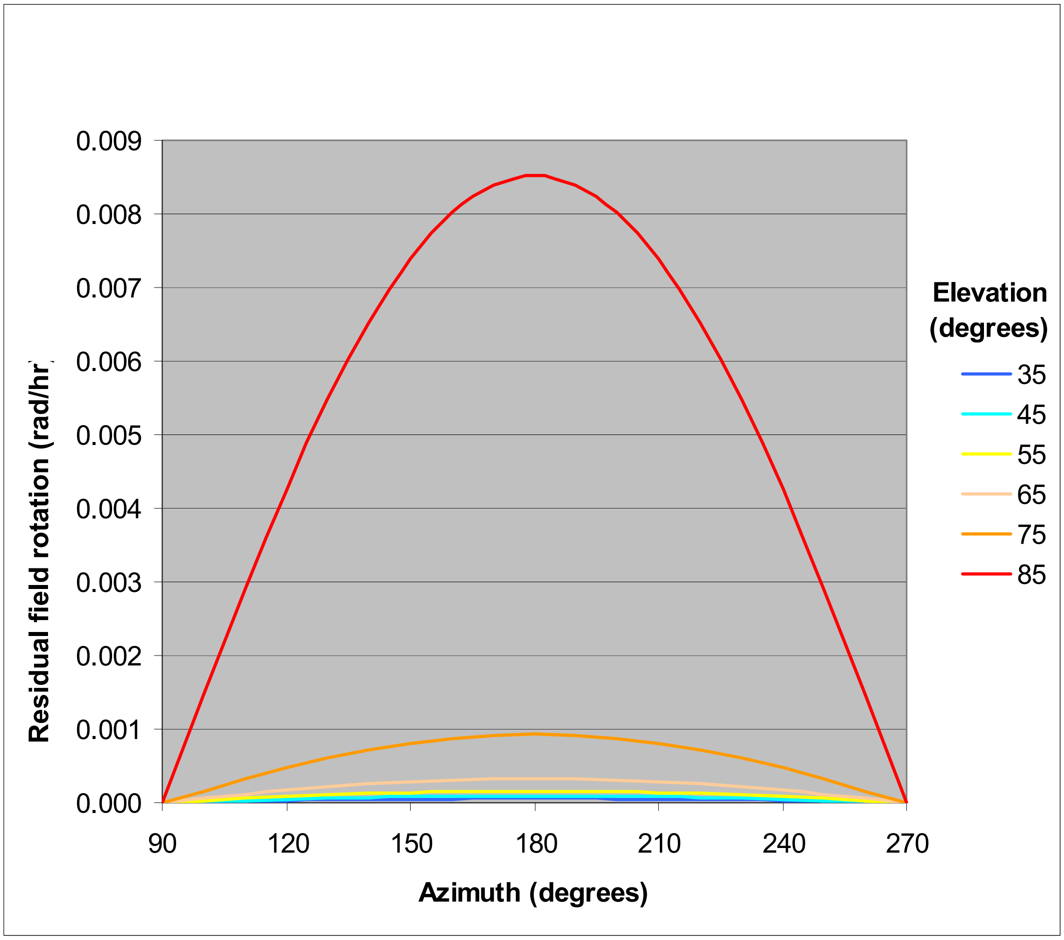

Figure 3: Differential field rotation rate for an assumed 1 arcmin altitude decentering of the telescope pointing and derotator axes.

In many respects, the assumptions made thus far and portrayed in Figure 3 comprise a worst-case scenario. A 1 arcmin misalignment of the pointing and derotator axes is quite large, corresponding to a linear offset of 17 mm in the *f*/9 MMT focal plane. Even so, for the assumed misalignment, the residual rotation rate $\Delta(d\eta/dt)$ is less than ~0.001 of the true field rotation rate $d\eta/dt$ except near the zenith. Furthermore, the worst-case zone, the cone above $a = 85°$, occupies <9% of the visible sky, and a zenith cap is excluded from pointing for every alt-az telescope because of the rapid azimuthal slew rates that are required for diurnal tracking. For the MMT, the "cone of avoidance" is defined by the maximum building rotation speed to be $a > 89°50'.6$ (Poyner 1992).

For guiding based upon the position of a single star in the field, the derotator is run open-loop (the rate is computed based on the telescope pointing position), and guider motions simply adjust the pointing to keep the guide star fixed in the image plane. This effectively translates any residual field rotation to an origin centered on the guide star, as sketched in Figure 4. Therefore, if $\Delta\theta$ is the angular distance between the guide star and the scientific target, the target will appear to orbit around the guide star with a velocity given by $\Delta(d\eta/dt) \cdot \Delta\theta$.

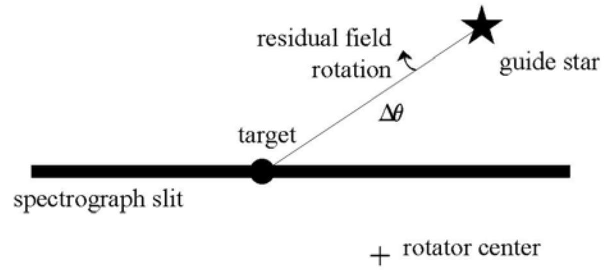

Figure 4: Schematic of focal plane for a star field registered to a single guide

Consider two representative cases, using a guide star located $\Delta\theta = 30$ arcsec from the target:

a) Still assuming a 1 arcmin axis misalignment, a telescope pointed at an elevation of 65° will experience a maximum residual field rotation rate when crossing the meridian (Figure 3) of $\Delta(d\eta/dt) = 0.00033$ rad/hr. Thus, a 1 hr exposure will see that the target is "trailed" by the insignificant amount $\Delta(d\eta/dt) \cdot 1 \text{ hr} \cdot \Delta\theta = 0.00033 \cdot 30 = 0.01$ arcsec!

b) The worst case considered here: a telescope with 1 arcmin axis misalignment observing an object crossing the meridian at an elevation of 85°, yields a displacement of the target of just 0.25 arcsec in a 1 hr exposure.

Note that the displacement is reduced for a guide star located closer to the target, and a more realistic axis misalignment of, say 10–20 arcsec, causes even the above small displacements to be reduced by a factor 3–6.

Conclusions

For reasonable attempts at coaligning the pointing axis of an alt-az telescope with the axis of the instrument derotator (<1 arcminute), and target elevations below ~80°, the effects of residual field rotation are negligible during realistic exposure times. There is some premium on selecting guide stars located near in the field to the target of interest, but star trailing due to differential field rotation is <0.1 arcsec in a 1 hr exposure over virtually the entire sky. For well-characterized instruments like the MMT Spectrograph, whose slit center is well within 1 arcminute of the rotator axis, the traditional setup time spent on identifying the rotation axis in the field of view is better spent on gathering scientific data.

References

Poyner, A.D. 1992, MMTO Technical Memorandum 92-1

Smart, W. M. 1962, Spherical Astronomy, (Cambridge: Cambridge University Press), p. 55