ENGINEERING MEMO No. 150

FINE-GUIDANCE SYSTEM FOR ARECIBO TELESCOPE

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September 27, 1983

Mike Davis has sent me his conceptual design (Upgrading Memo 83-P1) of a Ground-Referenced Fine-Guidance System. Its goal is to improve the pointing errors of the Arecibo telescope, which are about 20 arcsec at present. The desired measuring accuracy of the suggested guidance system is 3 arcsec. Mike asked for comments and suggestions.

The basic ideas of the system look very good. A reference on the ground is the proper choice, because the pointing is effected only by dislocations of the focal equipment, not by its rotational deformations; we thus must measure the focal translation with regard to the primary reflector, and the latter is fixed to the ground. Second, this new system is to be used in addition to the old one to which one can fall back in case of failure. Third, if the old system is always used simultaneously, the new one can be limited to fine-guidance and thus needs only a very small field of view.

We have discussed it already in the past, but I want to mention it again: the statement that only focal translations matter but not rotations will hold also for future Gregorian mirror systems under one condition. The combined system of secondary, tertiary and feed must (in first order) rotate as a rigid body about the point of the paraxial focus, under all deformations considered. I think this will hold in a good approximation, because the combined system is fixed at the carriage house, surrounding the focus. The target of the guidance system must then be again close to this focus.

In our NRAO designs of tiltable telescopes it was mostly the rotational deformations which mattered for the pointing, but we still preferred to have a ground-referenced system, which then is a bit more complicated, needing a reflecting target in the structure and autocollimation on the ground. Frequent blocking by moving members asked for a good redundancy, with seven stations on the ground. This made it expensive, to be recommended only for larger telescopes as for the 65-m design, but not for the 25-m design.

The errors caused by the atmosphere were measured at Green Bank with a test-version of the instrument, over a distance of 185 ft at an elevation angle of 14°. Under bad conditions (hot and calm air, sun) we found an rms error of 0.6 arcsec, with a narrow high peak of the power spectrum near 1 Hz, falling to half the maximum at 3 Hz. The design and the tests are described in our blue book: "A 65-Meter Telescope for Millimeter Wavelengths", Findlay and von Hoerner, 1972 NRAO. See Figs. 19 and 20. The 65-m telescope was designed for a total pointing accuracy of 2 arcsec.

Mike suggested to have a light (or infrared) source as a target close to the paraxial focus, and to look at it with a TV camera on a theodolite from the primary vertex, where the brightest pixel of the camera defines the two measured coordinates: the errors of azimuth and zenith distance of the vertex angle. But if the main purpose of the system is not so much a measurement of the error but its reduction to <u>zero</u>, then I think the camera and its equipment could be replaced by a much simpler and cheaper quadrant-photometer, used as a null-indicator. We still are able to measure the pointing deviations of the old system with such a null-indicator: first, we point the telescope to a given location using only the old system; then we switch on the new guidance system in order to obtain the corrected location, and we record the telescope movement between uncorrected and corrected locations.

The suggested theodolite at the vertex measures only two angles: azimuth and zenith distance of the target at the feed. This would be sufficient if the deformations were always limited to the focal sphere, see Fig. 1. But if the carriage house moves normal to the sphere, toward the primary or away from it, then it seems we need, in addition to the two angles, a distance measurement.

Suppose the undeformed original target position is at T in Fig. 1, with the telescope pointing at zenith angle z. The original vertex angle v then is, as shown by Mike,

$$\tan v = \frac{\sin z}{2 - \cos z} \tag{1}$$

and since the pointing is structurally limited to $z \leq 20°$, we have $v \leq 17.9°$ from (1). Now, let the focal structure deform normal to the focal sphere, moving the target from T to T'. This does not change the pointing z; but the theodolite sees a deviation Δv, it assumes the feed has moved from T to T" on the focal sphere, and thus it will ask for a pointing correction Δz which is wrong. This error can be avoided if the distance d is measured (modulated laser beam and reflecting target) and if its change Δd is recognized. We use the following relations from Fig. 1:

triangle	yields	
V T C	$\gamma = v + z$	(2)
T T' T"	$\tan \gamma = \Delta s/\Delta F$	(3)
T T" C	$\Delta z = \Delta s/F$	(4)
T T' A	$\cos \gamma = \Delta d/\Delta F$	(5)

Equations (3) and (4) give the pointing error Δz caused by the deformation ΔF in the absence of a distance measurement:

$$\frac{\Delta z}{\Delta F/F} = \tan(v+z) \leq \tan 37.9° = 0.778. \qquad (6)$$

If the pointing specification demands $\Delta z \leq \Delta z_m$, then this effect can be neglected only if $\Delta F/F \leq \Delta z_m/0.778$; or, with F = 435 ft and demanding Δz_m = 3.0 arcsec, only if

$$\Delta F \leq 2.5 \text{ mm.} \qquad (7)$$

If the deformations normal to the focal sphere are larger than (7), then a distance measurement is needed. Its accuracy Δd is derived from (5) as $\Delta d = \Delta F \cos \gamma$, and it must be $\Delta d \leq 2.5$ mm cos 37.9°, or

$$\Delta d \leq 2.0 \text{ mm.} \qquad (8)$$

This distance measurement is possible, but it may be considered an unpleasant complication. Instead of, we could also find the wanted vertical deformation by an angular measurement from a second theodolite. But if this is near the vertex, both theodolites would need an extremely high accuracy; and if it is far away from the vertex, we have a blocking problem, and we would at least need a third theodolite for the present line feeds, and one or two more for future Gregorians.

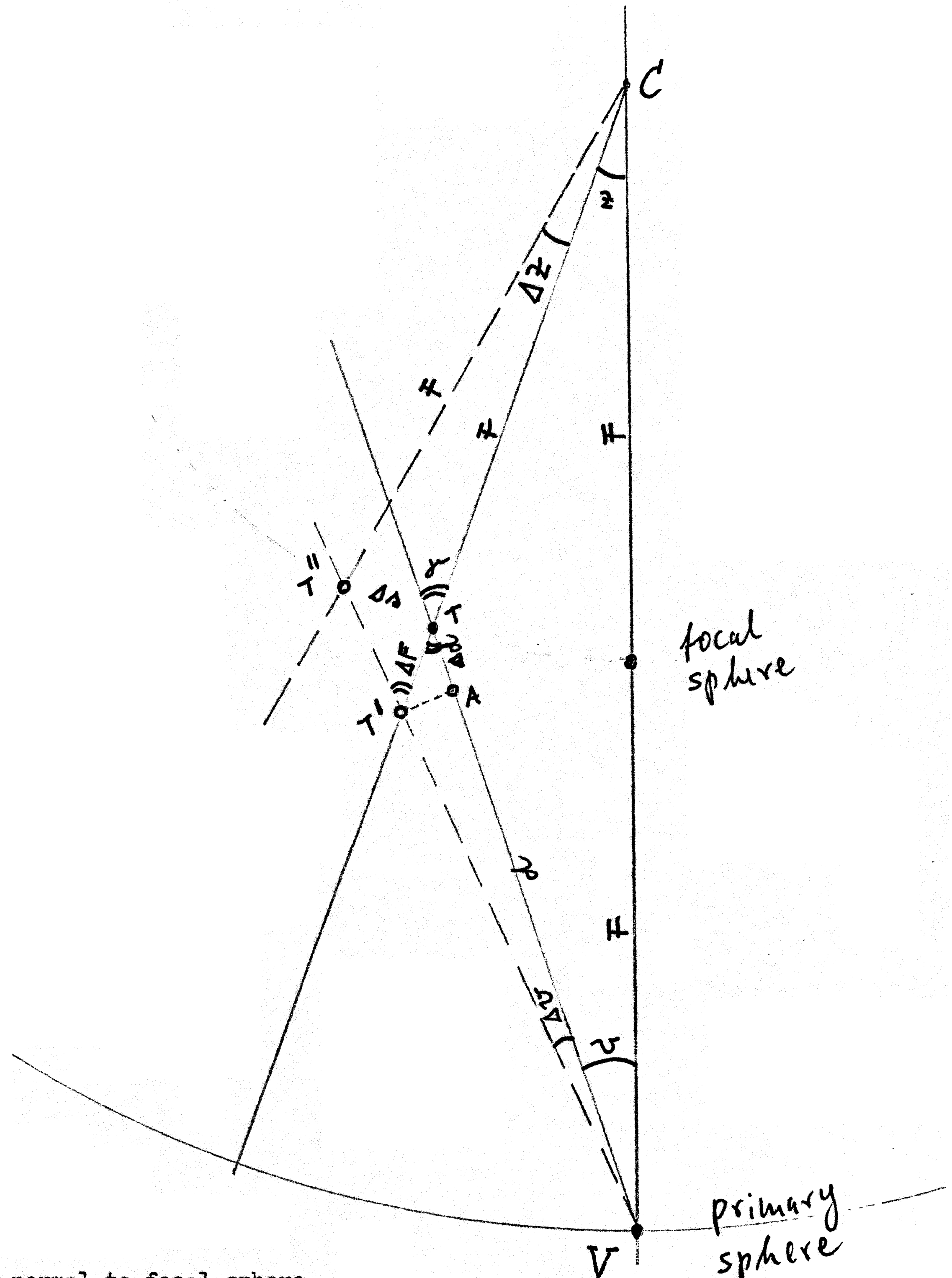

Fig. 1. Deformation normal to focal sphere.

F = focal length, C = center of curvature, V = primary vertex.

The focal target was originally at T and is deformed to T'. Without distance measurments, the theodolite at V assumes the target to be at T", causing a pointing error Δz. This is avoided if distance d is measured and its change Δd is recognized.