NATIONAL RADIO ASTRONOMY OBSERVATORY
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AZIMUTH ROTATION AND DEFORMATION OF QUADRIPOD

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ABSTRACT

Some comments are given regarding the measurements by D. Weber (Memo of 5-6-81) and L. Temple (Memo of 6-30-81). Tiltmeter readings at yoke base and top, during azimuth rotation of 360°, show disturbingly large nonplanar distortions up to 20 arcsec amplitude at the yoke top where it matters for pointing (and 2 - 3 times larger at yoke base), with a dominant term of sin (3α). The main features repeat in two runs four days apart, but the differences are still larger than tolerable, 10 - 28 arcsec. Repeated measurements during several calm nights, at two antennas (one shielded?) are suggested. An apparent hysteresis of 5 - 10 arcsec is more probably just a slow change in the thermal deformation of the pedestal.

Thermal displacements of the quadripod top were measured from the elevation shaft, during a mostly sunny day, with $\Delta\phi$ = 15 - 29 arcsec peak-to-peak. This amount, as well as $\Delta\phi$ as a function of time, agrees fairly well with a theoretical estimate. Additional measurements of the thermal Cassegrain rotation are suggested, in order to decide whether the quadripod legs would need thermal shielding, too.

I. AZIMUTH ROTATION

L. Introduction

Tiltmeters were installed at Antenna 6, and readings were taken while the antenna rotated 360° forth and back in azimuth, in steps of 45° (Dave Weber, Memo of 5-6-81). The original purpose of the test was to compare the inexpensive bubble tiltmeters with the better but expensive Schaevitz tiltmeters. Four of each kind were mounted, one bubble and one Schaevitz together, two such pairs at the yoke base and two at the yoke top, measuring tilts about the y-axis (parallel to the elevation shaft) and the x-axis (perpendicular to it).

As described by D. Weber, the bubble meters behaved fairly well at the yoke base, but were too wind-sensitive (above 10 mph) at the yoke top, and he recommended against their future use. He mentioned, too, that the measurements showed strong distortions and maybe a small hysteresis. I would like to add some remarks. The following will refer to the Schaevitz readings only.

2. Non-planarity

Without any distortions, the azimuth drive should rotate the yoke about a steady axis, defining an exact plane of rotation. Ideally, this plane would be horizontal, and all tiltmeters would read zero all the way round. With an axial misalignment, the plane would still be a plane but slightly tilted, and the meters would read an exact <u>sine</u> wave, identical for base and top of the yoke, and with x-readings of the same amplitude as the y-readings but shifted by <u>90°</u> in azimuth.

If the azimuth drive were done with wheels on a circular track, then a somewhat nonplanar (bumpy) track would cause a somewhat distorted sine wave, where the x-distortions may be different from the 90°-shifted y-distortions, depending on the locations of the wheels and of the tiltmeters.

If only three wheels are used, then the tilts of base and top must again be identical. If there are more than three wheels, then the structure of the base will show internal deformations, averaging the single wheel movements, and thus the yoke top can only show this averaged smaller tilt while any meters mounted at the yoke base may show the larger individual movements.

If the wheels are not located equidistantly along the circular track, or if the internal stiffness of the yoke base is different in x and y-direction, then the amplitude of the distortions may be different for x and y-readings.

We consider the bumpiness of the track developed into a Fourier series. Then the first-order terms, $\sin(\alpha)$ and $\cos(\alpha)$, represent the planar tilt. The second-order terms, $\sin(2\alpha)$ and $\cos(2\alpha)$, cannot show up as a tilt (at least not in the average tilt of the top) because of their symmetry. The third-order terms, $\sin(3\alpha)$ and $\cos(3\alpha)$, are the first terms which may show up as non-planar distortions. Fourth-order cancels again because of symmetry, and only odd-order higher terms may be seen. Since amplitudes mostly decrease with order, we expect the distortion to be mainly of third order.

3. Observations

A first test for planarity was done by D. Weber, and his main results are combined in our Fig. 1. If x and y-readings are sine waves of equal amplitude with 90° shift, then plotting y over x should yield an exact circle (or a horizontal ellipse because of the different scales used). Fig. 1 shows three things: the presence of strong distortions, which are larger at the base than at the top of the yoke, and which look similar four days later.

As a second test, we plot the x-readings over azimuth together with the 90°-shifted y-readings, two days on one sheet; Fig. 2 for the yoke top and Fig. 3 for its base. We see again the distortions, very clearly, at base larger than at top, in x larger than in y, well repeating four days later, at least qualitatively. And the dominance of the third-order terms is quite obvious, especially at the larger base deformations. The amplitude of the distortions is up to 20 arcsec at the yoke top, and 2 - 3 times larger at the yoke base.

The quantitative 4-day repeatability is not as good as one would hope. We find typical differences of

$$\begin{array}{l|cc} & \text{base} & \text{top} \\ \hline \text{x-axis} & 22 & 28 \\ \text{y-axis} & 10 & 18 \end{array} \Bigg\} \text{ arcsec} \qquad (1)$$

4. Conclusions

The 4-day differences may have been caused by thermal deformations. We would like to see a new set of measurements, taken at several calm nights, to answer this important question of the repeatability.

The nonplanar distortions could be caused by manufacturing inaccuracies of the azimuth bearing; they would then be constant in time but probably different for each antenna. However, the specifications had called for an accuracy of 1 arcsec. Or they could be caused by asymmetric thermal deformations from sun and shadow; they would then be similar for all antennas but a complicated function of time and sky. However, the 110-inch diameter bearing and its mounting are so sturdy and solid that an internal warp from the pedestal tubes, propagating through plates and bearing into the yoke base, is hard to imagine. Nevertheless, something does happen and we ought to find out what. We would need new observations, at several calm nights and at <u>two</u> different antennas.

If repeated new observations confirm the problem, what can we do about it? If it is of a thermal nature, it should hopefully go away with proper thermal shielding of the pedestal. If it comes from manufacturing and stays constant in time, each antenna would need four additional pointing parameters: $\sin(3\alpha)$, $\cos(3\alpha)$, for x-tilt, and y-tilt. Or, one could mount tiltsensors on top of each yoke and use their readings for real-time pointing corrections.

5. Hysteresis

The measurements show some difference, typically of 5 - 10 arcsec, between the forward rotation through 360° azimuth and the return rotation. But I would not call it a hysteresis, because that would be a one-sided lag while the observed difference mostly changes sign twice in 360°. This indicates a small change in the tilt direction of the azimuth plane which could be caused, for example, by thermal deformation which is a function of time. Also, the sign of the difference is in some cases different for both observing days.

Furthermore, a healthy structure just <u>cannot</u> show any hysteresis, on principle grounds. Hysteresis can only be caused by pathological things like extremely heavy friction, by a loose joint (as once found out at the 300-ft), by a wrong design with coplanar joints and oil-canning, by plastic deformation of over-stressed members, or the like. Thus, a true hysteresis would indicate severe trouble of some sort. Again, new observations at night would help to clarify this question.

II. THERMAL DEFORMATION OF THE QUADRIPOD

1. Observations

A theodolite was mounted on the elevation shaft of Antenna 21, looking up at two apex points: subreflector mirror, and a target on a bar between two legs (L. Temple, Memo of 6-30-81). The antenna pointed always at zenith, while rotating in azimuth such that one quadripod leg (the "down leg") tracked the sun. Readings were taken every hour between 07:00 and 20:00 on June 24. Also recorded were air temperature, wind, and sky cover. Results are copied in Fig. 6, showing considerable deformations, of 15 arcsec peak-to-peak for the mirror and 29 for the target. The large differences between the two points, especially in the afternoon, may be difficult to explain.

The measured angular displacement, $\Delta\phi$, is not directly equal to a pointing error. For prime focus observation, the error would just be $\Delta\phi$ times the beam deviation factor. But for the actual Cassegrain observation, $\Delta\phi$ measures only the lateral displacement of the subreflector, while its (not measured) rotation will yield another error term of similar order. If wanted, the subreflector rotation could also be measured from the shaft location, using autocollimation.

2. Theory

In VLA TEST MEMO 129 (Jan. 1981) we have already given an estimate for $\Delta\phi$ which we now want to compare with the observations. For the geometry of Fig. 4 we derived

$$\Delta\phi \quad = \quad \frac{1}{2} C_{th} \, \Delta T \left(\frac{2h}{b} + \frac{b}{2h}\right). \tag{2}$$

For the worst case, where one leg is exposed to perpendicular sunshine and the opposite leg is completely shadowed, we expected $\Delta T = 5°C$ and

$$\Delta\phi_{max} \quad = \quad 19 \text{ arcsec}. \tag{3}$$

This agrees well enough with the measured 15 - 29 arcsec peak-to-peak displacement.

For a more detailed comparison, we use the elevation of the sun, E, which also was recorded every hour by Temple. We use the illumination angles from Fig. 4:

$$\alpha = E + 48.4°, \qquad \text{and} \qquad \beta = E - 48.4°. \tag{4}$$

We assume that the sun is tracked accurately such that the "down leg" will cast shadow on the opposite leg for low elevations of the sun, and we then expect, with $\Delta T = T_a - T_b$,

$$T_a = 5°C \sin\alpha, \qquad \text{and} \qquad T_b = \begin{cases} 5°C \sin\beta, & \text{for } \beta \geq 0, \\ 0 & \beta \leq 0. \end{cases} \tag{5}$$

Inserting (5) with (4) and (3) into (2) would yield $\Delta\phi$ as a function of the sun's elevation and thus of time, but this would hold for higher elevations only, while atmospheric extinction becomes important for lower elevations. After inspection of textbooks and a rough estimate, we replace the 19 arcsec of (3) by 20.8 arcsec times $e^{-0.09/\sin E}$ and obtain

$$\Delta\phi = 20.8 \text{ arcsec } e^{-0.09/\sin E} \begin{cases} (\sin\alpha - \sin\beta), & \text{for } E \geq 48.4°, \\ \sin\alpha & E \leq 48.4°. \end{cases} \tag{6}$$

This theoretical $\Delta\phi$ is plotted as a function of E in Fig. 5, and as a function of time in Fig. 6. It shows a fairly good qualitative agreement with the observations, especially for the mirror and the deep minimum at 13:00.

For the future, we should discuss the possibility of measuring the subreflector rotation, too. And if the combined error is larger than to be tolerated, we may consider thermal shielding also for the legs.

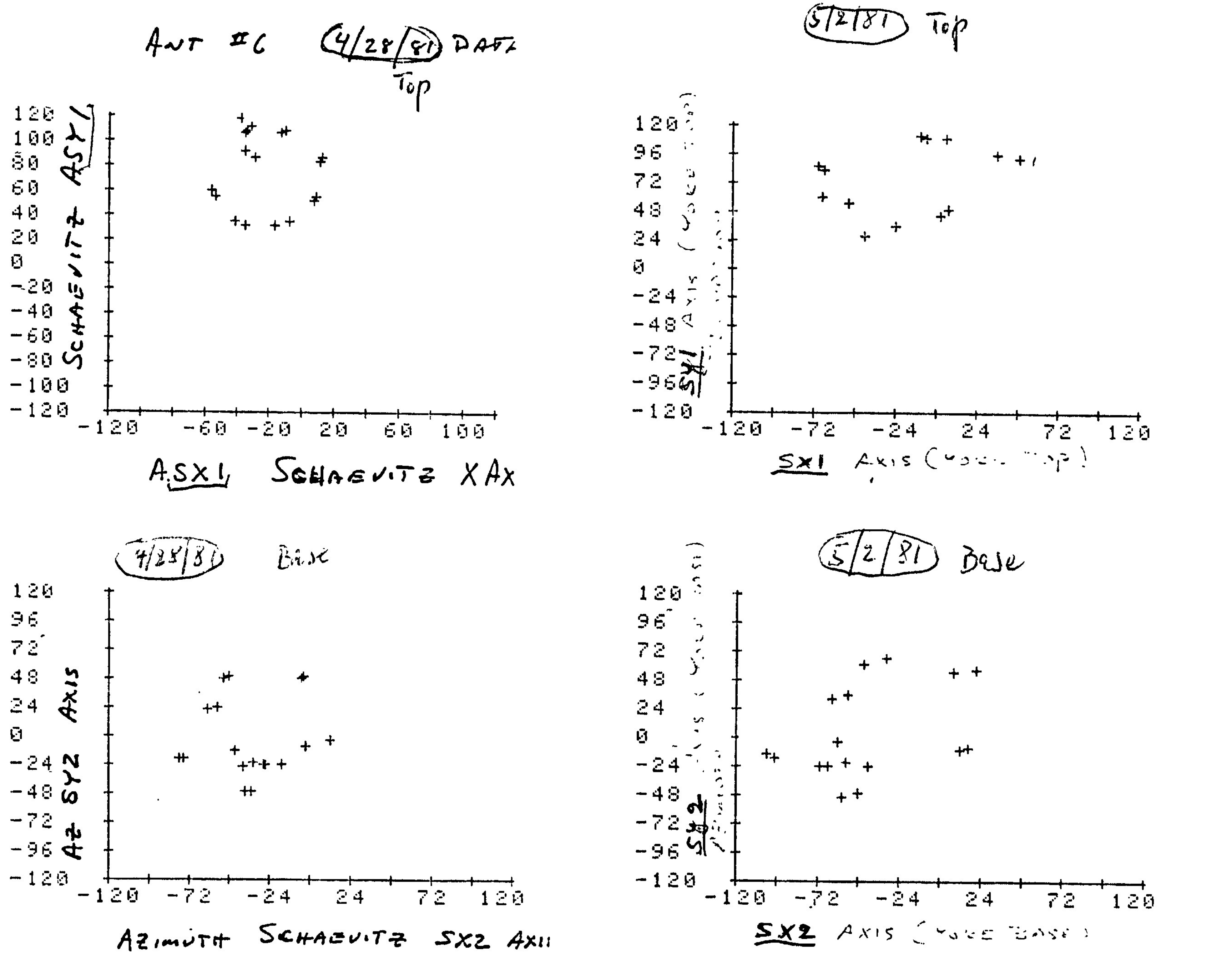


Fig. 1: First test for planar azimuth rotation. The readings of the Schaevitz tiltmeters, for tilts about x-axis and y-axis, should describe a circle. Antenna 6, top and base of yoke. (From Memo of Dave Weber, May 6, 1981.) These plots have different scales for x and y, thus the circles should appear here as horizontal ellipses.

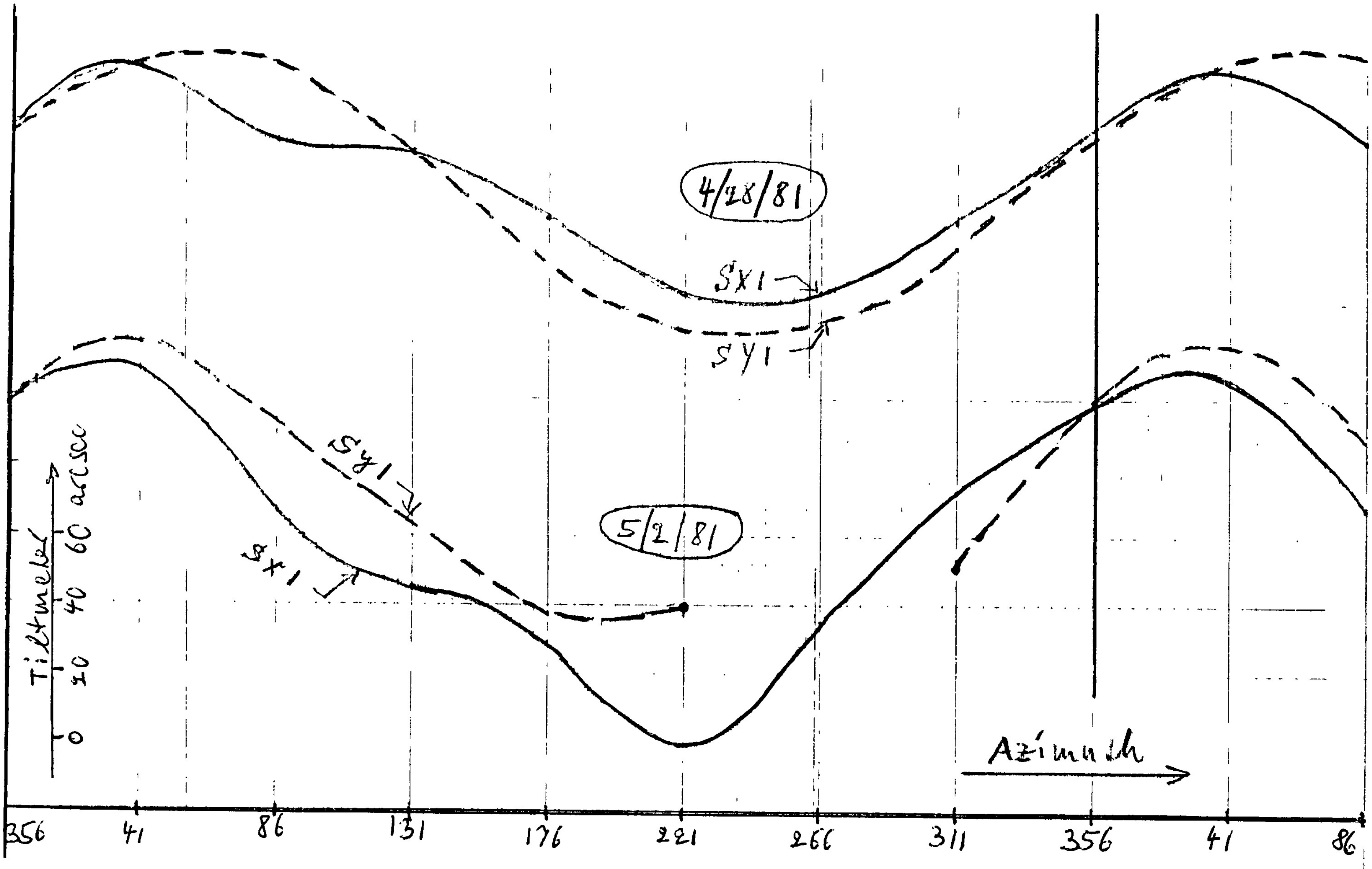


Fig. 2: Second test for planar azimuth rotation. The y-readings are here shifted by 90° in azimuth and should then agree with the x-readings; and both readings should describe simple sine waves. (Same data as in Fig. 1.) Figs. 1 and 2 are also a test for repeatability, for data taken four days apart. Top of yoke. One data point missing at 266°.

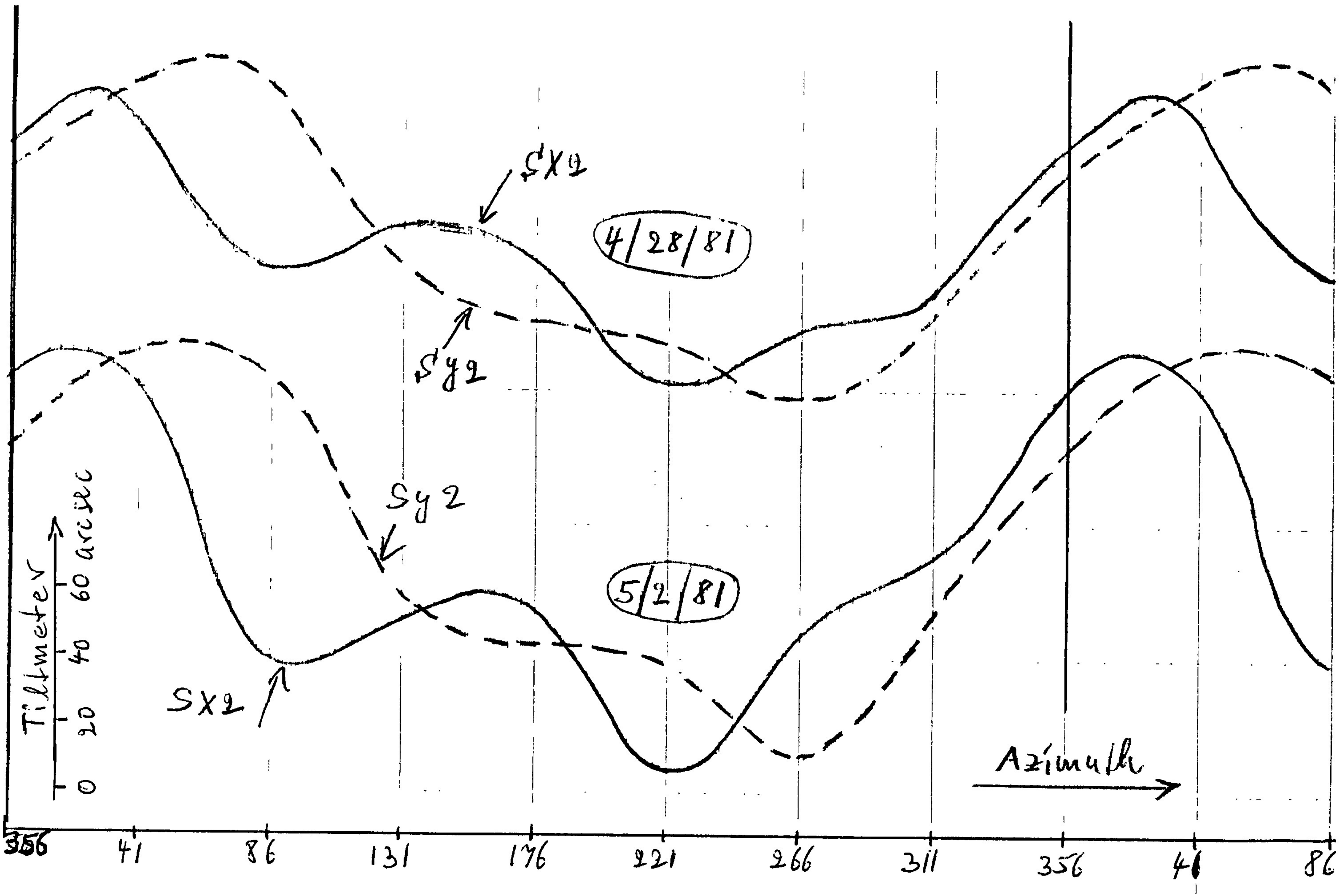
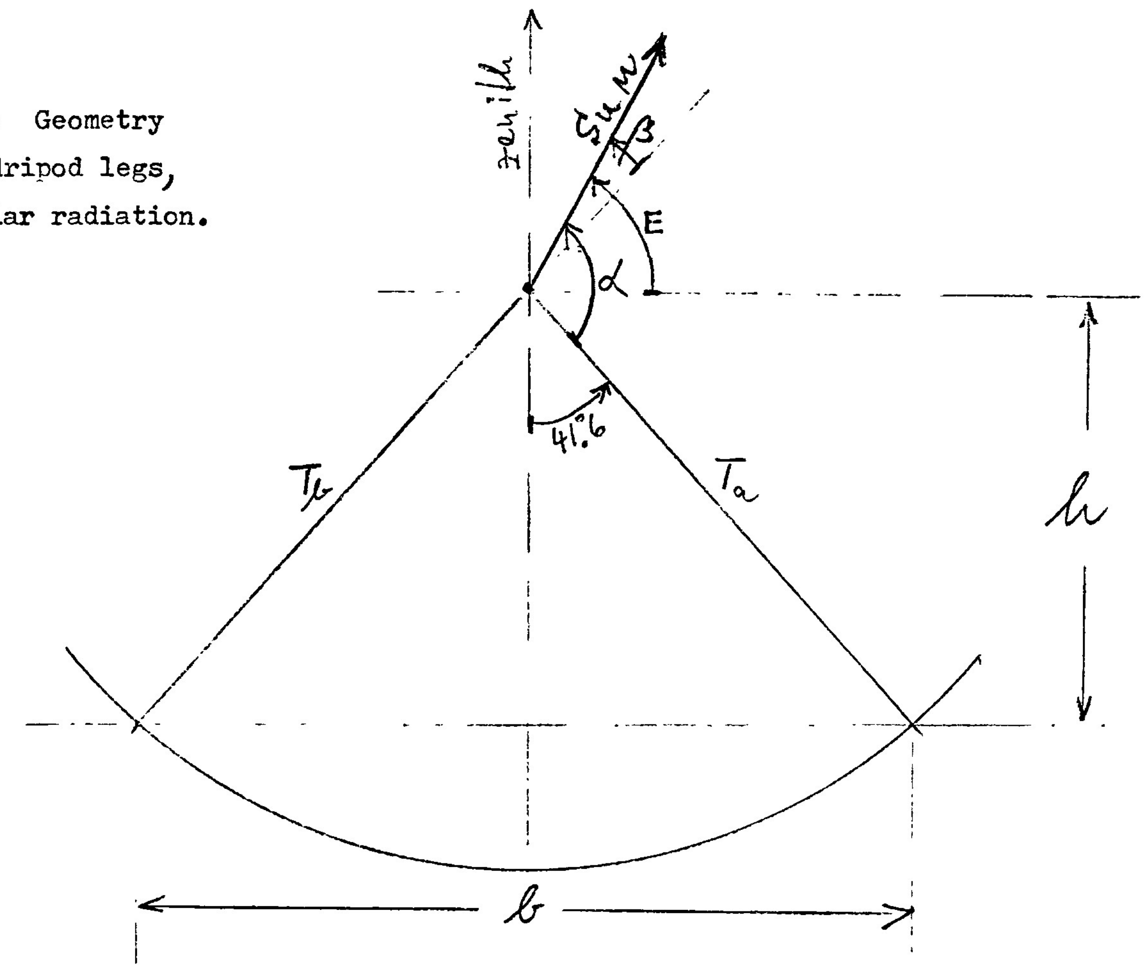


Fig. 3: Same as Fig. 2, for base of yoke.

Fig. 4: Geometry of quadripod legs, and solar radiation.



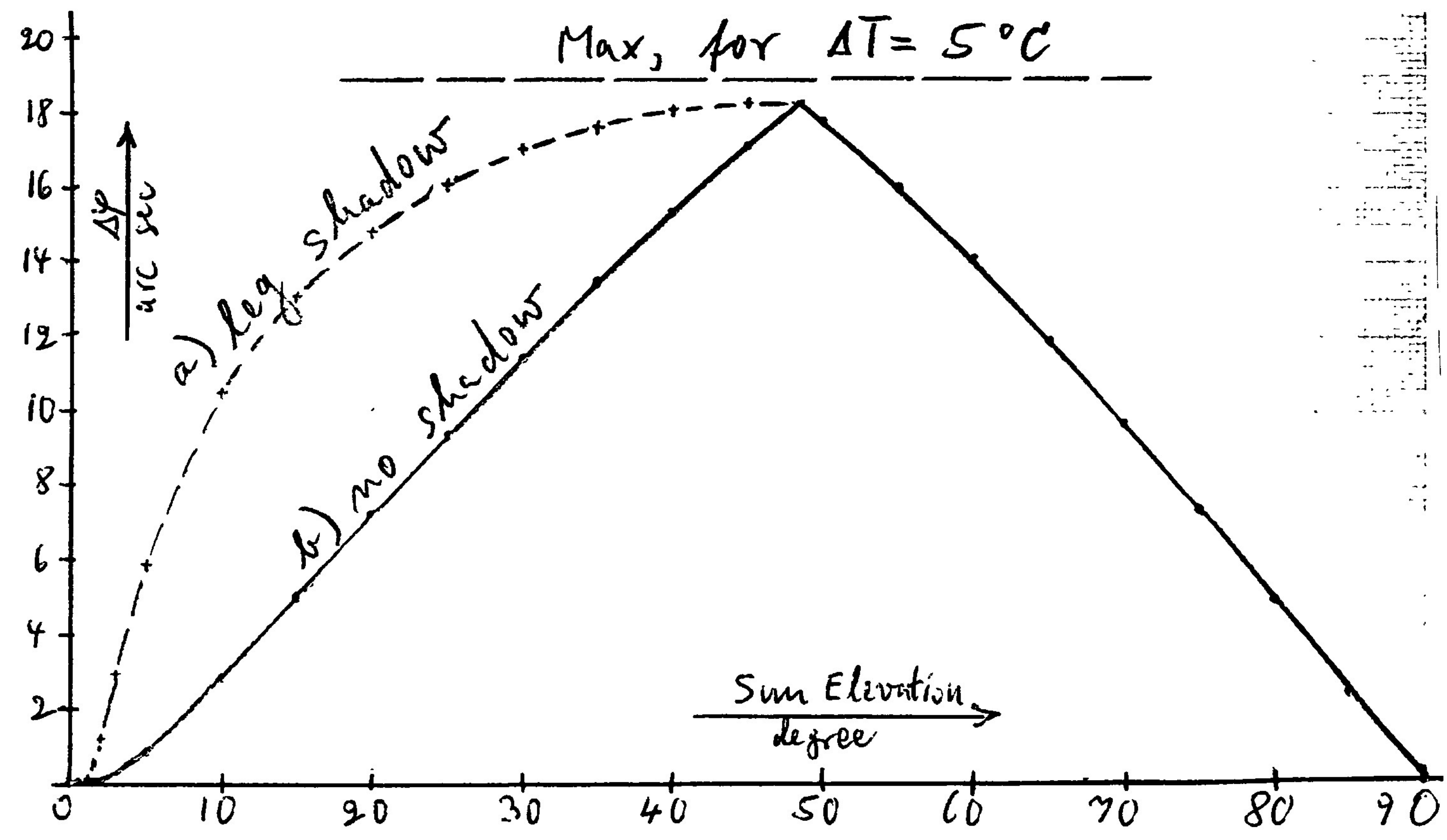


Fig. 5: Resulting pointing error Δφ. a) In test run June 24, the azimuth was tracking the sun, one leg shadowing the other. b) Normally, no shadow.

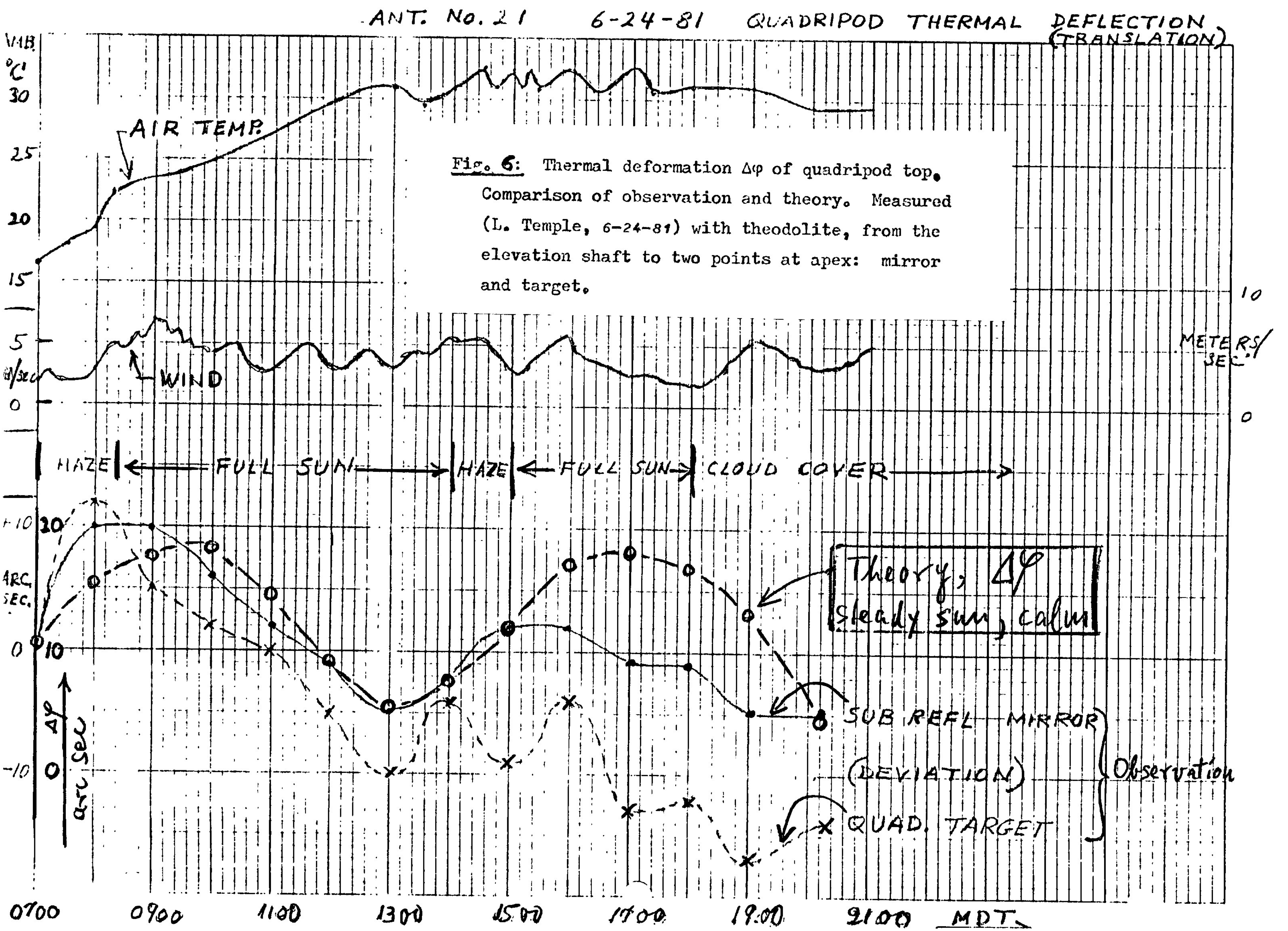


Fig. 6: Thermal deformation Δφ of quadripod top. Comparison of observation and theory. Measured (L. Temple, 6-24-81) with theodolite, from the elevation shaft to two points at apex: mirror and target.