A NEW METHOD FOR ZENITH DISTANCE DETERMINATION IN MERIDIAN OBSERVATIONS

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In meridian observations, the main error sources of the declination observation reside in determination of the atmospheric refraction, the flexure of the telescope and the division errors of the graduated circle. In order to obtain higher accuracy in the declination observation, besides a full automation device, the photoelectric meridian circle at Tokyo Astronomical Observatory (Tokyo PMC) is equipped with photoelectric devices for circle reading and a zenith mirror in addition to the conventional mercury horizon. We report here on a preliminary determination of the horizontal and vertical flexures, and of the division errors of the glass circle.

1. Division Errors of the Graduated Circle

The Tokyo PMC is equipped with six telecentric microscopes for circle reading. Two fixed pairs of microscopes are attached at the fixed angle $90^\circ.0$ to each other and are used for routine observations. In addition to these pairs, the PMC has a movable pair of microscopes for the determination of the graduation errors.

All six microscopes are provided with a device for illuminating the graduations from behind, a photodiode array, and a microprocessor. On every setting of the circle, each microscope reads out five divisions projected on the array, which is composed of 1024 elements with 25 μm width each. The imaging scale of each microscope is about 13.5 and the width of each division is about 20 μm on the circle (glass circle with 3600 divisions).

A scheme for an accurate determination of the division corrections in the fully automated photoelectric meridian circle has been proposed by Miyamoto and Ishii (1982) and Miyamoto and Kühne (1982). Based on this scheme, we examined $0^\circ.5$-, $40^\circ.0$-, and $43^\circ.2$-rosette measurements on 22 - 24 August 1983. For three independent rosette measurements, only two fixations ($40^\circ.0$ and $43^\circ.2$) of the movable pair of microscopes suffice. Because, during the measurements for the $40^\circ.0$- and $43^\circ.2$-rosettes in steps of four divisions, a counterpart of the fixed pairs could furnish simultaneously a complete set of measurements for the $0^\circ.5$-rosette. The small

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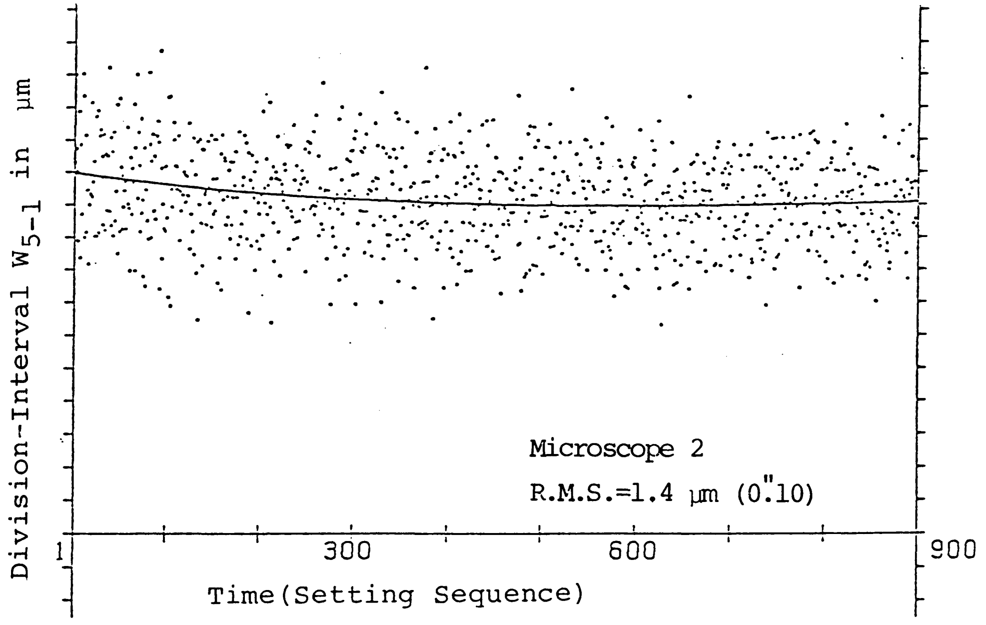

Figure 1. See the legend on the next page.

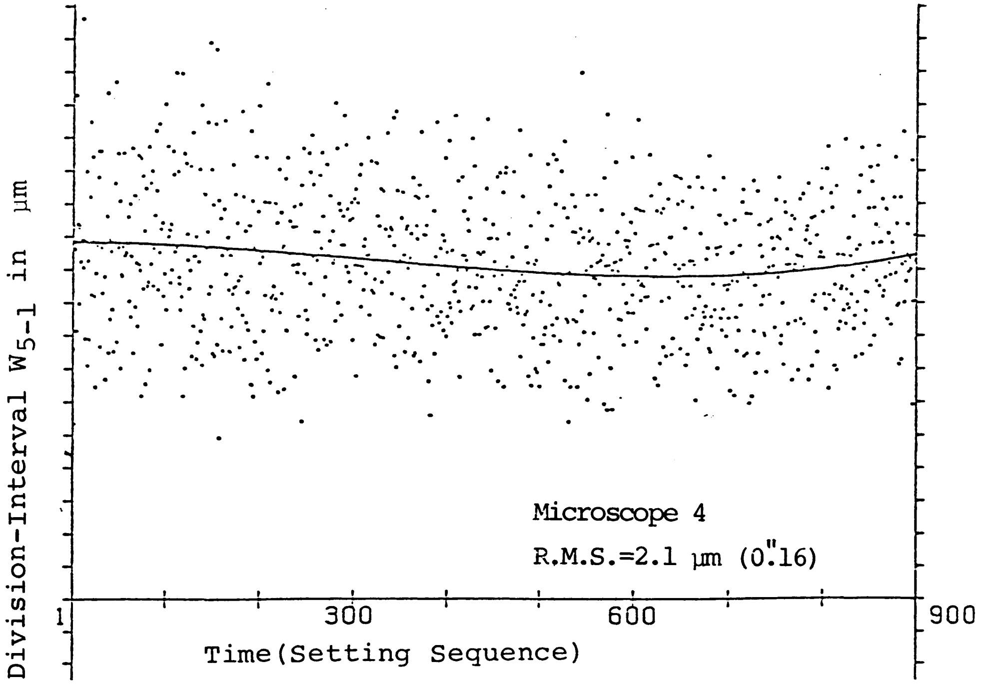

Figure 2. See the legend on the next page.

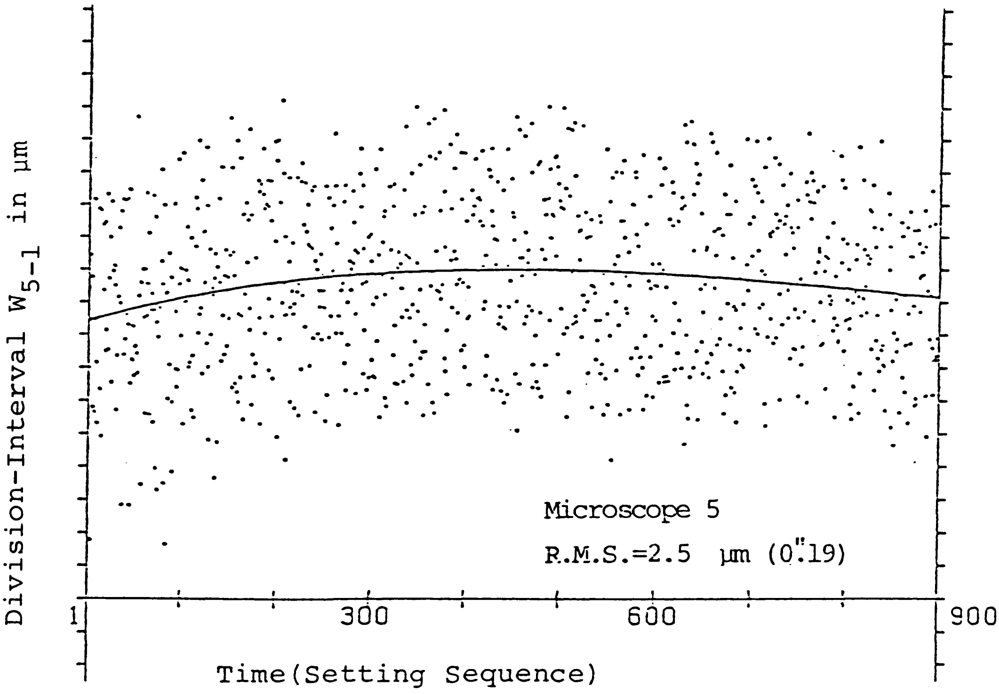

Figure 3. Variation of the division-intervals between the 1st and 5th divisions in the field of view of the indicated microscope, during the 40°.0-rosette measurements. The nominal interval between the 1st and 5th divisions is 19200 µm. The division readings have been executed in steps of 4 divisions, according to a random setting of the circle (Miyamoto and Kühne 1982). There are 900 division-intervals (plots) in each figure. The best-fitting curve (in the present case, 3rd degree polynomial) is also drawn in each figure. The curve is used for estimating the microscope-scale at respective circle setting. The R.M.S. value in each figure indicates an error estimate of the division readings by a photoelectric device.

angle $0\overset{\circ}{.}5$ was automatically subtended in the two consecutive fields of view of the same microscope.

In each set of the rosette measurements, 1800 diameters were measured twice by exchanging the role of two microscopes in a pair. Therefore, contrary to the traditional operation, each microscope reads out all the 3600 divisions. This process is indispensable for separating the illusory variation of the microscope-scale due to the division errors from the actual one due to, for example, the temperature change during the measurements (Miyamoto and Kühne 1982). The two fold measurement of 1800 diameters took about 13 hr and 9 hr for the $40\overset{\circ}{.}0$- and $43\overset{\circ}{.}2$-rosettes, respectively. To close one group measurement, it took about 7 min and 15 min for the $40\overset{\circ}{.}0$- and $43\overset{\circ}{.}2$-rosettes, respectively.

In the two nights during which we made our measurements, the temperature remained nearly constant (25°C ± 1°C), nevertheless we could notice a gradual variation of the microscope-scale. The variation is, of course, peculiar to each microscope. Three examples of the variation in the $40\overset{\circ}{.}0$-rosette measurements are illustrated in Figs. 1 - 3, in which the ordinate denotes the division-interval (in μm) between 1st and 5th divisions in the same field of view of a microscope, and the abscissa the setting sequence (equivalent to the time sequence) of the circle. In each figure, the statistically best-fitting curve (in this case, 3rd degree polynomial) is also drawn. The best-fitting curve $W_{5-1}(T)$ was used for estimating the respective microscope-scale

$$S(T) = 0\overset{\circ}{.}4 \times 60' \times 60''/ W_{5-1}(T)$$

where S(T) is the scale factor which converts the readings in μm to second of arc, and $W_{5-1}(T)$ the division-interval at the respective setting T. Thus, we have established a practical method to find the scale variation free from division errors in a long duration of the rosette measurements. The scatter of the plots in each figure indicates an error estimate (experimental error) of the division readings in μm, which is about $0\overset{''}{.}15$ in the mean for all the microscopes.

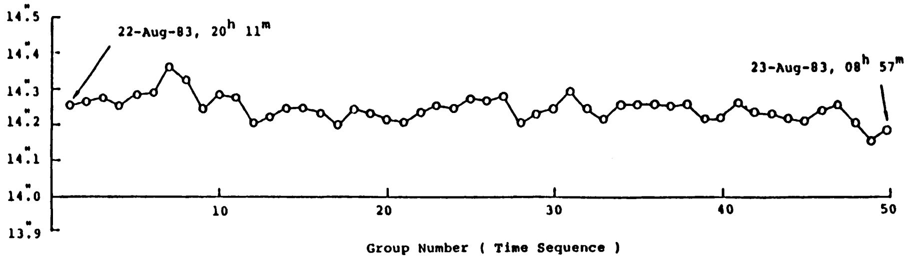

Figure 4. Variation of the angle subtended by two pairs of microscopes in $40\overset{\circ}{.}0$-rosette measurements.

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To determine the diameter corrections it is required to assume that the angle subtended by the movable and fixed pairs of microscopes be kept constant within every group of the rosette measurements. The angle can be accurately determined after completion of each group of measurements. Fig. 4 shows that the variation of the angle within each group is tolerable.

After the preparatory procedures above mentioned, we have analyzed all division readings of 3600(divisions) x 6(microscopes) x 3(rosettes), according to the scheme described by Miyamoto and Ishii (1982). First, we obtained 1800 diameter corrections, and then 900 circle corrections by taking the mean of corrections for 10 diameters which are $90^\circ.0$ apart from each other. Fig. 5 demonstrates the behavior of the diameter corre-

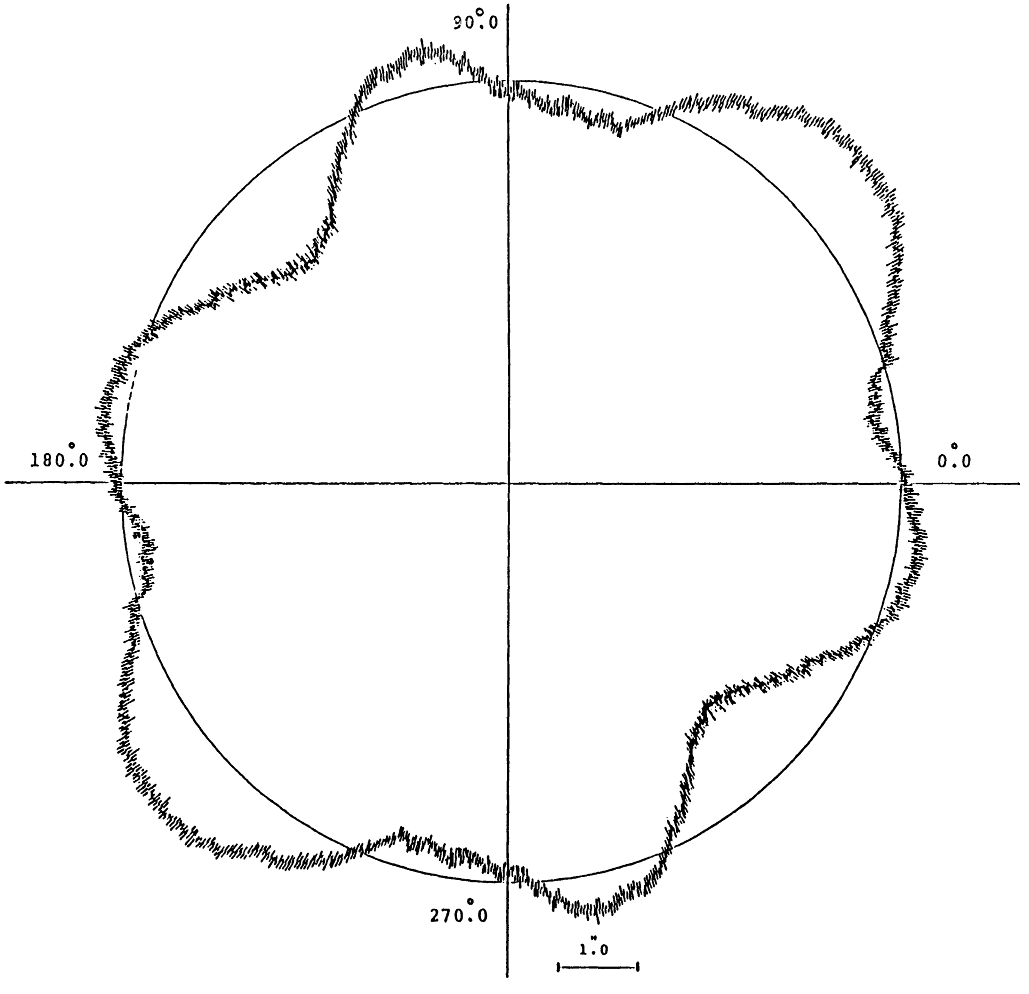

Figure 5. Diameter corrections around the circle.

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ctions around the graduated circle. The maximum amplitude of the diameter corrections is about 1".0 . A notchy pattern with a period of 4 divisions and with an amplitude of about 0".2 is superposed on the coarse undulation with a period of about 600 divisions. There appears a remarkable hexagonal feature of the circle distortion, which is considered to be caused by the method of fastening the glass circle to the telescope axis.

The circle corrections are similarly illustrated in Fig. 6. The maximum amplitude of the corrections is about 0".3 . There remains still a notchy pattern with a period of 4 divisions and with an amplitude of about 0".03 . The symmetry of the circle distortion (Fig. 5) is so remar-

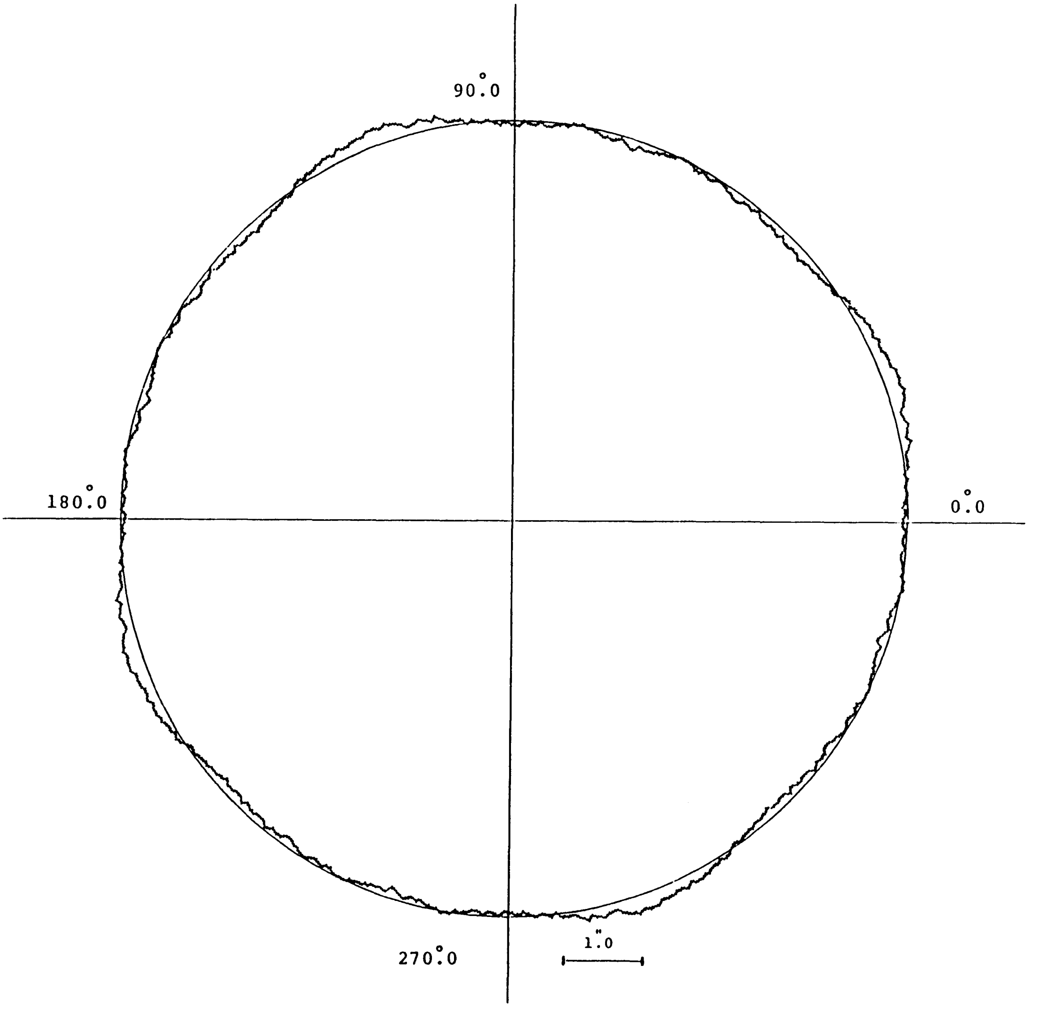

Figure 6. Circle corrections, which will be applied to routine observations.

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kable that the circle corrections are decreased to about 0".3 . The same is true for the notchy pattern.

The notchy pattern of the corrections would disappear, if the 0°.5-rosette measurements were excluded from the analysis : In the analysis of the 0°.5-rosette measurements, the diameter difference of 5 divisions apart from each other are derived from the division readings in two consecutive fields of view of the same microscope. Therefore, it is quite possible that the 0°.5-rosette measurements pick up the image distortion in detail (the scale variation in the same field of view) of the microscopes. The supplier of the PMC, Carl Zeiss Oberkochen, assumed that there remained about 0.4 % image distortion in the reading microscopes. The hardware and software of the microscopes are now being improved. For the time being, we are performing measurements for another practical combination of three rosettes with the angles 37.5, 40.0, and 43.2 (Miyamoto and Ishii 1982). In order to establish a final set of circle corrections, we are accumulating further independent sets of rosette measurements. The comparison of the two independent sets of analysis will be found in Miyamoto and Suzuki (1985).

2. The Flexure

The angle obtained from the readings of the graduated circle does not correspond to the angle of rotation of the line of sight of the telescope, in general. The discrepancy (the flexure) depends on the altitude of the telescope. The Correction F_z for the flexure at the circle reading z is represented formally by the Fourier series(cf. Podobed 1965).

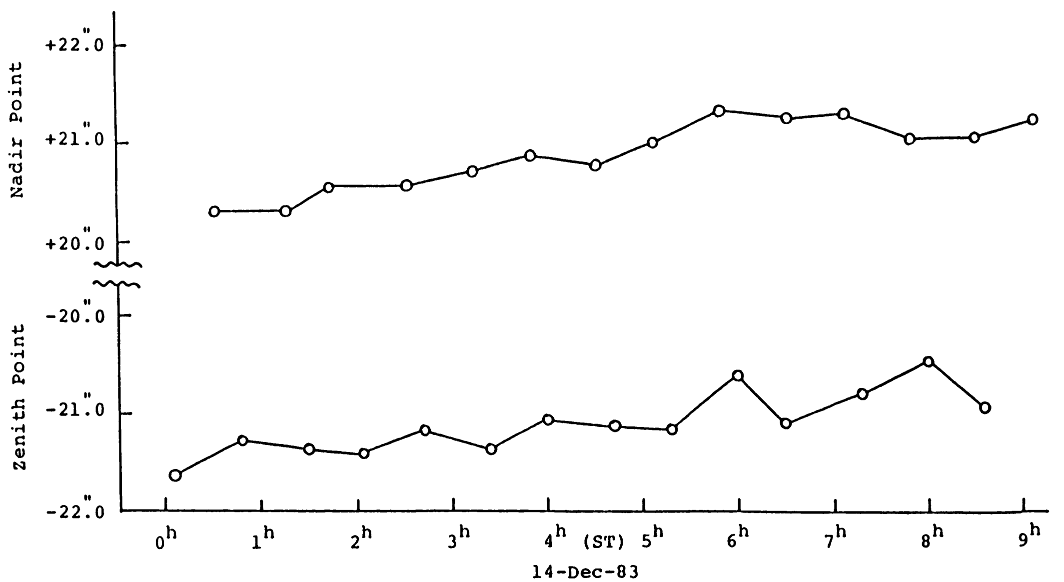

Figure 7. Determination of the nadir and zenith points.

Namely,

$$F_z = a_1 \cos z + b_1 \sin z + a_2 \cos 2z + b_2 \sin 2z + \cdots .$$

The cosine terms in the flexure may be eliminated by reversing the circle position (by setting the telescope in "Circle West" and "Circle East") for every observation. The "horizontal flexure" b_1 is usually determined by making use of the north and south collimators.

If we can determine the "vertical flexure" a_1 directly by a laboratory method similar to the one for b_1, we can make observations with higher accuracy and higher efficiency. To realize this idea, we have introduced the Zenith Mirror for the PMC. The zenith mirror is a plane mirror of 20 cm diameter with a perpendicular downward normal. The mirror is suspended on a thin wire and its swinging is damped aperiodically or nearly aperiodically by a cylinder immersed in oil. The mirror can be rotated through 180° about its vertical axis by means of a motor drive. The thin carrying wire has such a low resiliency that the average of the mirror normal in both positions coincides precisely with the actual zenith direction. During the measurement, the mirror is moved to a position above the telescope.

The same principle as for the determination of b_1 is applied for determining a_1 by combining the mercury surface and the zenith mirror. Fig. 7 shows how nicely the nadir and zenith points of the PMC are determined. The mean errors of single determination of the nadir and the zenith points are about 0.″05 and 0.″1, respectively. To be noticed here is a parallelism in the variation of the two independent sets of measurements. Fig. 8 shows the daily determination of the vertical flexure a_1 and the horizontal flexure b_1. The horizontal and vertical flexures

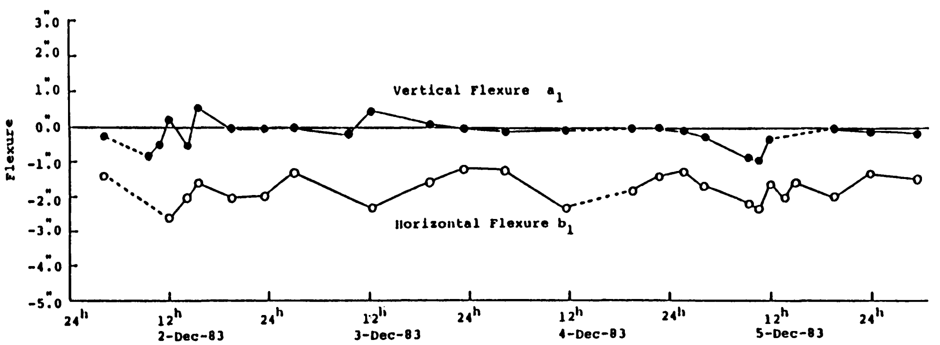

Figure 8. Variation of the horizontal and vertical flexures.

of the PMC stay close to the values of about $-1''.5$ and $-0''.3$, respectively. That is, the vertical flexure of the PMC is quite small.

The authors express their gratitude to their colleagues in Meridian Astronomy Division of the Tokyo Astronomical Observatory for the intensive operations of measurements. Thanks are also due to Messrs. H. Hara and H. Ishii, who helped us to analyze the data for division errors.

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Discussion:

BENEVIDES-SOARES: How long does it take to observe the $0^\circ.5$ rosette?

MIYAMOTO: This was performed simultaneously with the 40° rosette and the $43^\circ.2$ measurement. In our instrument the microscope can see every 5 divisions, so some kind of a chain-method could be applied.

HUGHES: The solid state array method of reading the circle appears to be quite good. At the U.S. Naval Observatory, we are also experimenting with a method similar to the Tokyo approach and it is likely that solid state reading will become the general method of choice.