THE OSCILLATING SLIT MICROMETER OF THE MERIDIAN CIRCLE PMC 190 TOKYO

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ABSTRACT

The meridian circle installed at the Tokyo Astronomical Observatory in 1982/83 is equipped with a photoelectric Double Slit Micrometer which is one of the basic prerequisites for fully automatic observation. A slit plate is located in the image field of the telescope. It oscillates parallel to right ascension while being guided at the mean traveling speed of the star.

The paper describes the procedure by which the moment of the star passage through the instrument's meridian and declination is determined. Furthermore, the autocollimation devices are described which are an essential prerequisite for the determination and periodical checking of the instrumental errors.

Also, the measuring devices for the passage of the sun and the moon are dealt with briefly.

1. INTRODUCTION

The Double Slit Micrometer was introduced in 1972 by the first author during the engineering phase of the meridian circle project. The concept is based on the multislit micrometer used by E. Høg (1970) at the meridian circle in Perth. The $\pm$ 45° inclination was retained, but the multitude of slits was replaced by only one movable pair. Therefore, the system became independent of the star's velocity, a higher degree of statistic averaging could be applied, and a more simple and stable kind of collimation measurement became available.

2. DESIGN PRINCIPLE

The telescope of the PMC 190 has a double-walled tube whose inner part houses the objective and the section of the micrometer which has to per-

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form the precision measurement. The outer part of the tube protects the interior against temperature gradients and supports the multiplier section of the micrometer whose positional accuracy is not important (Kühne 1983).

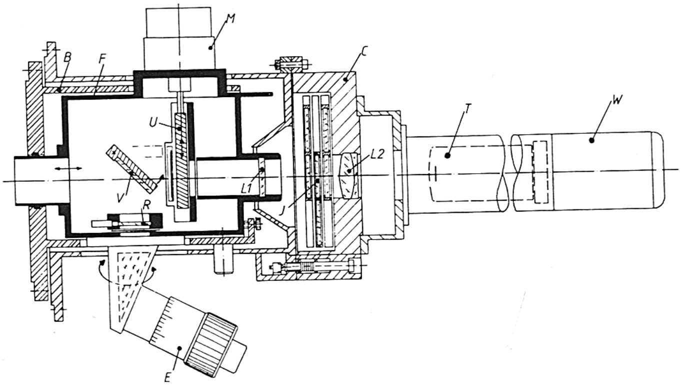

Fig. 1: Double Slit Micrometer, Section

The micrometer (Fig. 1) consists of housing B which is flanged to the inner wall of the tube. Inside, another housing F can be shifted along the optical axis for focusing. After focusing, however, it is permanently screwed together with B, thus forming a constructional entity with B. F accommodates the motor (M)-driven micrometer slide U. The slit plate P (Fig. 2) which is supported by U is located directly in the telescope's image plane.

For visual observation, mirror V can be swung into the beam path. The image plane then lies in an illuminated reticle R which is observed through eyepiece E. For the observer's convenience the eyepiece is angled and adjustable.

The star light passing through the slit plate reaches the cathode of a photomultiplier via a lens L1, a set of filters J, and a doublet L2. In space W, behind the multiplier, the discriminator for the photons to be counted, a pre-amplifier, and the high-voltage transformer are installed. This ensures that the feeder cable for the most part is not prone to interferences and need not carry high voltage.

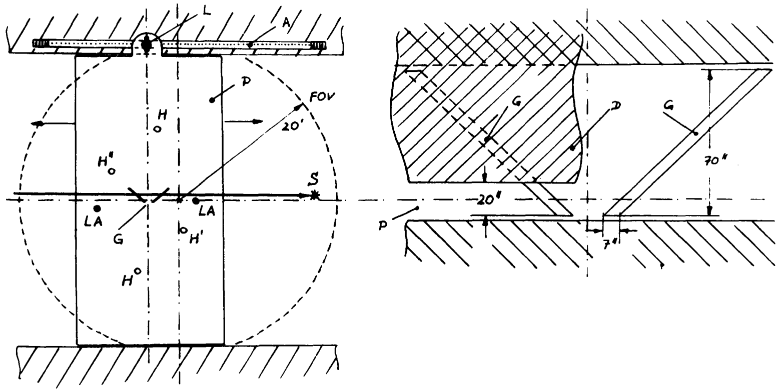

Fig. 3 shows the micrometer on the telescope of the PMC 190, with the multiplier housing C turned off

Fig. 2: Image Plane with Micrometer Plate

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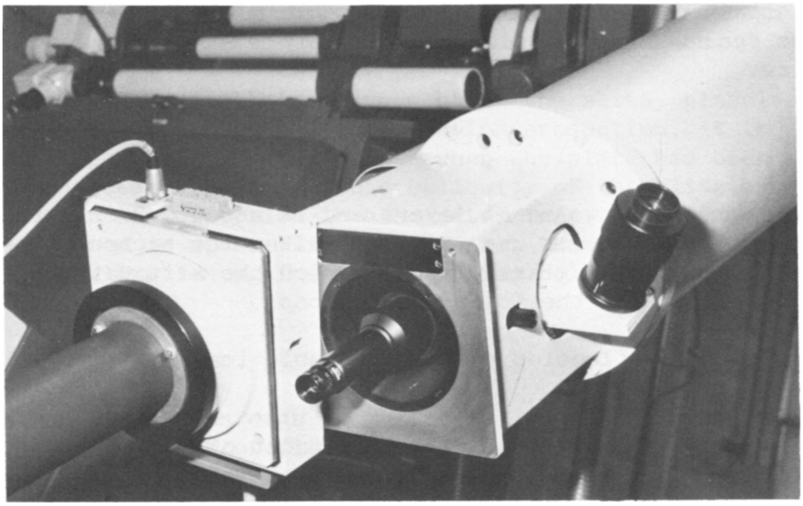

Fig. 3: Double Slit Micrometer, opened

3.OSCILLATING SLIDE

The slide runs on precision rails parallel to right ascension axis. It is driven by a controllable D.C. motor which directly drives a spindle. Unlike many other micrometers, however, the spindle is not used for measurement. Instead, the position of the slide is measured by a photodiode array A (RL 1024 C Reticon line scanner) which is mounted on the stationary part of the micrometer housing (Fig. 2). The oscillating slide supports a luminescent diode L which flashes with each Real Time Clock Pulse (RTC) of 50 ms and illuminates a small part of the array through a narrow slit. Immediately after the flashing, the array is scanned and the position of the slit image on the array is thus measured.

The width of one array element is 25 μm (2 arc sec) which means that the resolution would be much too coarse. Therefore an electronic interpolation method is applied which works as follows: The scan frequency of the array (250 kHz) is derived from a 16 x basic frequency through frequency division. At the rate of the scan frequency the photometric intensities of the individual array elements are first fed to a sample-and-hold device where they are stored for a short time. Then they are filtered analogously and scanned with the basic frequency. The latter is transferred to two counters which count the pulses from the scanning start up to where a specific trigger level on the front flank of the intensity function is exceeded. This value is recorded by the first counter. The second counter advances up to the trigger level of the rear flank. Both values are added, thus giving the position of the slit plate with a 32 x resolution, i. e. in units of 0.78 μm (0. 063 arcsec).

This method is insensitive to amplitude fluctuations, and the timing is well defined because of the briefness of flash of 10 μs. The measuring accuracy attained in practice for one single position reading is 2.5 μm (0.2 arc sec) which includes approximately 1.2 μm (0.1 arcsec) electronic noise.

4. SLIT PLATE

The slit plate is made of two metal layers and is about 0.2 mm thick. A special etching technique was used for the slits. The technologically simple method of producing a glass plate on which the slit pattern is deposited was abandoned for the following reasons:

- in spite of anti-reflection coatings, double images will inevitably occur;
- in spite of a 99 % protective filter in front of the objective, the incoming energy during solar observation leads to a heat build-up, due to the poor thermal conductivity of the glass.

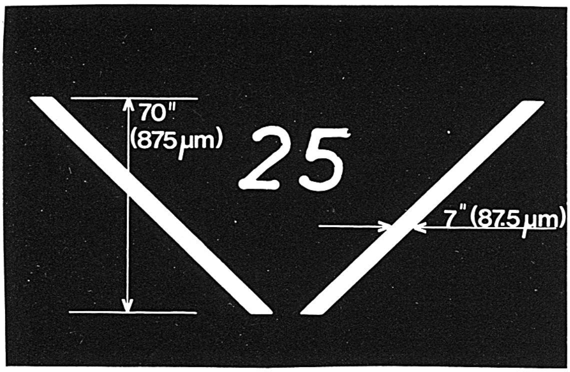

Fig. 4: Slit Plate,Microphotograph

Fig. 4 shows the slit pair (real microphotograph!) The width of the slits parallel to the oscillating direction is 87.5 μm (7 arcsec), the height is 875 μm (70 arc sec). The height has been chosen so that the scanning of the largest planet Jupiter is just possible. For the observation of stars, the upper part of the slit can be covered by a remotely controlled diaphragm down to a residual height of 250 μm (20 arc sec) (see Fig. 2).

The slit width has been adjusted to the diameter of the seeing disks of the stars to be expected in Mitaka, i. e. to approx. 4 arc sec on the average. The effective aperture at a right angle to the slit is approximately 5 arc sec. It may therefore be expected that in a star passage the full light passes the slits at least for several RTCs. This is prerequisite for the measurement of faint stars. On the other hand no prolonged saturation occurs by which the accuracy of the passage measurement would be unnecessarily reduced. The optimum width probably will have to be empirically determined. To permit the appropriate experiments, the PMC 190 is also equipped with slit plates of 5 and 10 arcsec slit width which can be interchanged as required.

Fig. 2 also shows that the slit plate has 4 pinholes H, H', H" of 30 μm (2,5 arc sec) diameter as well as two luminescent diodes LA. The pinholes are used for the measurement of sun and moon passages for which the slits are fully covered by the remote-controlled diaphragm. The luminescent diodes serve for autocollimation measurements.

Although the geometrical arrangement of the slits, pinholes and LED's are measured with high precision during production, it is still necessary to repeat these measurements when the plate has been installed. In this process, the inevitable obliquity of the slits in respect to the oscillation direction is also determined. Some of the measurements are performed in autocollimation against the nadir or zenith mirror, some in collimation against the meridian collimator.

5. PHOTON COUNTING

The light passing through the slits is imaged onto the cathode of a multiplier by means of field optics. Field lens L1 (Fig. 1) first produces a parallel beam path which is sent through a set of filters comprising an interference filter (λ_0 = 550 nm, $\Delta\lambda$ = 100) and two neutral density filters with attenuation factors of 60 and 3600. The filters can be remote-controlled independently of each other. The doublet L2, behind them, images the entrance pupil (objective) of the telescope onto the multiplier cathode with a diameter of approx. 7 mm.

The multiplier is of a type suitable for photon counting (EMI/9892 a/350) with a cathode diameter of 9 mm. Its specified dark count rate is 10 cps. The bialkali cathode has been adjusted to the desired range of sensitivity with a central wavelength of λ_0 = 550 nm.

The present status of technological development dictates the form of the shielding of the multiplier and its integrated circuits for high-voltage generation, the discriminator and the pre-amplifier stage. The threshold frequency of the discriminator is 10 MHz.

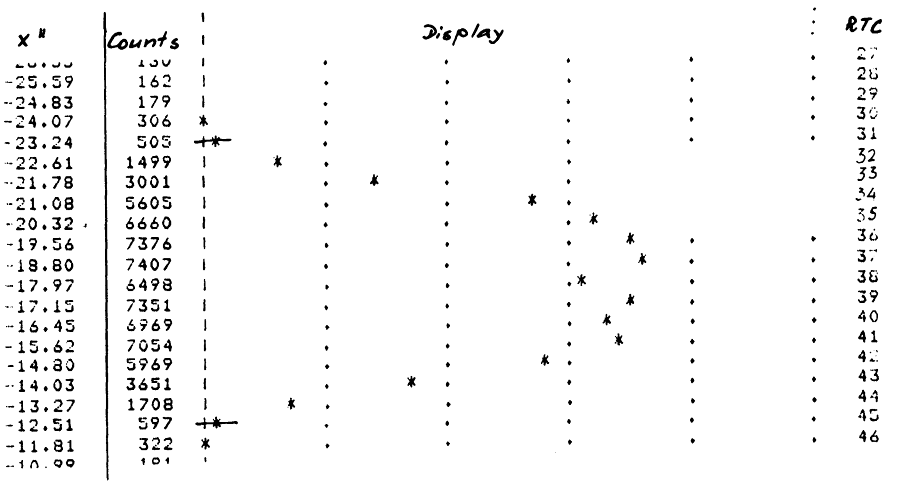

Fig. 5: Record of Star Passage

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Fig. 5 shows the typical recording of a star passage across one of the slits. The first column indicates the position data of the micrometer slide in arc sec. The second column indicates the counting rate. On the right is a graphical representation of the counting rate per RTC. On the far right, the numbers of the RTC's are listed, with the initial value being set by the astronomical clock in UT or ST as required.

6. STAGES OF A STAR PASSAGES

Fig. 6 shows the place-time diagram of a star passage. Apart from stars which are extremely close to the pole, the star moves in a more or less straight line and at a constant speed $\dot{x}_s$ across the image field, x being the fixed position coordinate of the telescope in parallel to right ascension. The slit plate oscillates with respect to the star so that the slits alternately cross the path of the star.

At the points marked with an asterisk the slit passages $t_{j,m}$ are recorded. Simultaneously with $t_{j,m}$, the positions x_j are recorded for each RTC. The method of obtaining these time data is described below. The speed of the slit plate has been chosen so that the relative speeds $\dot{r}$ of the slit plate and the star are idential in their amount in the positive and negative branches of the oscillation. Originally, $\dot{r}$ is 30 arc sec/sec but r is freely selectable within the limits set by the hardware

$$5 \leq |\dot{x}_s + \dot{r}| \leq 45 \text{ arcsec/sec}$$

From two coordinates $t_{j,m}$ belonging to a positive or negative branch the mean values are calculated:

$$t_m = \frac{1}{2}(t_{2,m} + t_{1,m})$$

$$\Delta t_m = \frac{1}{2}(t_{2,m} - t_{1,m})$$

The latter gives the declination differences $\Delta\delta_m$ beeing added to the

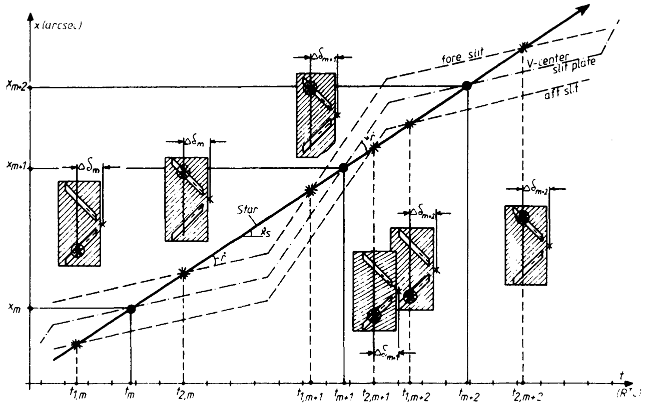

Fig. 6: Place-Time Diagram of a Star's Passage

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readings of the divided circle. Essentially, these are the heights of the star path in the V formed by the slits in relation to an autocollimation point of the instrument.

During a complete star passage which lasts 120 sec., up to 120 pairs (x_m, t_m) and 120 $\Delta\delta_m$ values are obtained. Through optimum adjustment of a regression line, the x_m and t_m values give the moment t_M when the star passed through the meridian point x_M of the instrument which is assumed to be known. $\Delta\delta_m$ is identical for all m values and may therefore be averaged.

$$\Delta\delta_M = \overline{\Delta\delta_m}$$

Of course the simple formulae stated here only apply to a geometrically ideal slit plate. In practice, error parameters have to be taken into account which are caused by the following factors:

- The angle bisector of the slits is not perpendicular to the oscillating direction.

- The slit angles deviate from $\pm$ 45 ° with respect to the bisectors.

- The oscillating direction is not exactly parallel to right ascension.

The systematic errors have to be determined and taken into account in the form of corrections in t_M and $\Delta\delta_M$. This is not a difficult task and hardly differs from the determination of comparable errors in conventional meridian circles. No representation of the error evalution was included here.

For the sake of completeness, it should be added that any irregularities in the movement of the slit plate have no effect at all and deviations in linear guiding only make themselves felt as a statistical error which, just like the image motion of the star, is eliminated through averaging, due to the large number of measurements.

7. DETERMINATION OF A SLIT PASSAGE

Basically, the procedure for determining the coordinates (x_m, t_m) of a slit passage is as follows: First, the moment $t_{i,m}$ is determined at which the "mean star" passed the centre of a slit, and afterwards t_m is used to calculate the coordinate x_m of the slit plate position which is assigned to this moment.

For the determination of a single slit passage $t_{i,m}$ there are several, widely different mathematical models. Without wishing to anticipate the experience to be gained in the future, the median method suggested by Høg (1970) has been implemented in a slightly modified version.

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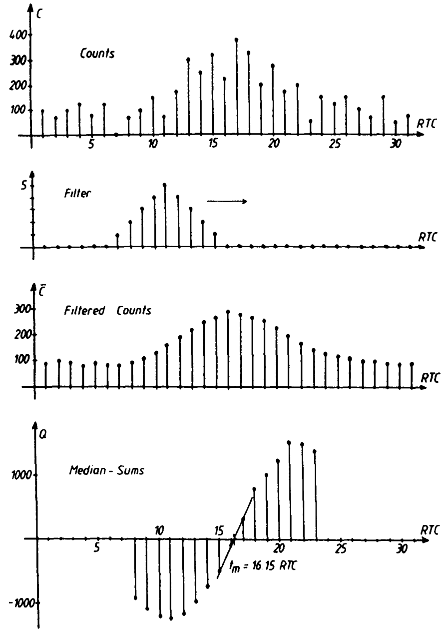

First, the counts occurring in each RTC are subjected to a dual sliding averaging process using 5 adjacent count values respectively. This smoothing corresponds to the filtering by means of a triangular function of height 5 and a base width of 9 RTC's (see Fig. 7). On the basis of the smoothed counts, the median sums Q, are calculated with 8 positive and 8 negative counts.

In the case of a slit passage, i.e. if a count sequence of sufficient lenght lies above the noise level, the median sums Q_i change their sign form negative to positive. Using 5 Q's in the vicinity of the change in sign, a linear regression is produced by means of which the exact moment t_m of the zero passage is determined.

Fig. 7: Treatment of Photon Counts

It is obvious that the consecutive Q's also continue as a result of the noise counts and that they change their sign irregularly. To be able to exclude these irregular changes in sign, the following criteria are applied:

- A change in sign is not acknowledged as a regular one unless at least 8 Q - values were negative before the change in sign and at least 8 Q - values are positive afterwards.

- The slit passages selected according to this criterion are not considered to be related to a star unless their significances S are identical with each other within 30 %. Significance is defined as the sum of the absolute quantities of the 8 Qs before and the 8 Qs after the change in sign.

$$S_i = \sum_{\nu=-7}^{8} |Q_{i+\nu}|$$

For each star passage identified by this method and characterized by moment $t_{i,m}$ the mean value t_m is calculated and the corresponding x-coordinate x_m is determined through interpolation. The latter is effected by means of a regression line which consists of 16 x-values, half of them before and half of them after t_m.

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8. THE AUTOCOLLIMATION SYSTEM

As shown in Fig. 2, 2 luminescent diodes LA are attached to the slit plate P which emit their light through small pinholes of about 30 μm (2.5 arc sec) diameter in the direction of the objective. They are the light sources for various collimation and autocollimation measurements. It is of special advantage that these light sources are fixed on the slit plate which means that the definitive geometrical relationship of the LEDs and the slits is thus established.

With respect to the α - components the relationship can be determined completely and without any further knowledge in autocollimation against nadir and zenith, with the instrument fully assembled. For the δ - components, the determination has to be done either on the basis of the coordinate measurement of the slit plate before installation or with the aid of the measurements taken in the reversed position of the PMC.

Since the LEDs are moved on the slit plate, the image points of the LEDs move as well during autocollimation, and moreover in the opposite direction, due to the image reversal of the optical system. The slit plate scanning such an image point therefore sees an artificial star which moves at precisely double the relative speed of the plate. If the oscillating speed is chosen to be 15 arcsec, the same relative speed is obtained which is used for the measurement of star passages.

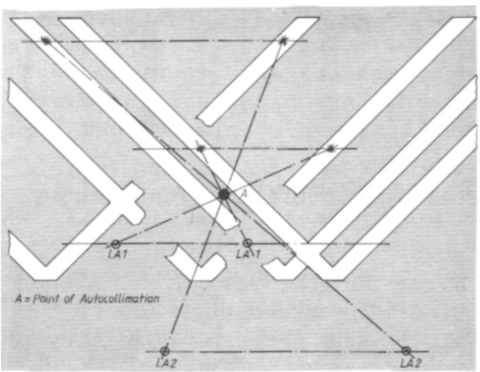


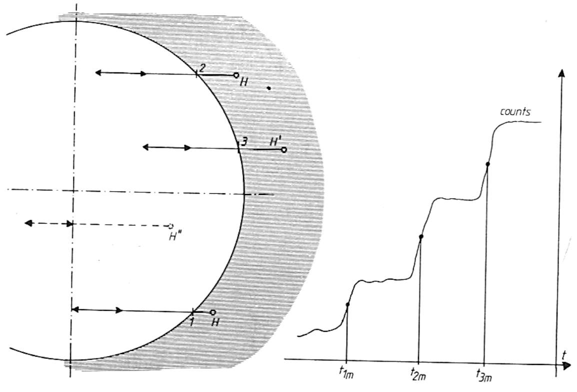
Fig. 8: Autocollimtion System

Fig. 8 shows the image geometry in autocollimation, A being the autocollimation point which acts as projection centre between the light sources, LA 1 and LA 2 and the image points assigned to these sources. The four positions of the slit plate are illustrated where each of the corresponding image points is just passing one slit.

9. THE PASSAGES OF SUN AND MOON

For this purpose the slit plate (Fig. 2) has four pinholes H, H',H". The slits and one of the pinholes H' and H" are covered by a diaphragm during the measurements. When the sun enters the field of view, the leading limb is measured first by means of the two pinholes H and pinhole H'. After the sun has crossed the meridian, a measurement is taken of the trailing limb, with H' being replaced by H". Fig. 9 shows the geometrical arrangement.

The height of the pinholes H has been chosen (M. Yoshizawa, H. Yasuda, 1982) so that they intersect the limb during oscillation at an angle of approx. 45°. H' is close to the solar equator. H" is covered and the distances to the x-direction are such that the pinholes cross the limb at approximately identical intervals, with allowance being made for the curvature of the limb.



The expected function of the count rates per RTC are shown in Fig.9 on the right. Since the pinholes have a diameter of only about 2.5 arcsec, the flanks are very steep. With a relative speed of the slit plate of 30 arcsec/sec, the flank theoretically lasts appromimately 1.7 RTC's (85 ms).

Fig. 9: Determination of Sun and Moon

The calculation of the passage is very similar to that of a star passage. In the case of the sun, only the inflection points of the function of the count rates shown in Fig. 9 need to be determined. This is done by two successive applications of Høg's median method.

10. ACKNOWLEDGMENT

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