COMMUNICATION FROM THE OBSERVATORY AT LEIDEN

On the photographic recording of circle positions, by G. van Herk.

1. The idea to register the positions of a divided circle on a photographic film seems to originate with J. Hartmann (V.J.S. 56, 99, 1921). The best known realization of this idea is the one made at Hamburg-Bergedorf. The results obtained with this instrument have been described in Astron. Abh. Hamburg-Bgdf 3, 132, 1937 by F. Dolberg and J. Larink. The Askania Werke has constructed a meridian circle fitted with an elaborate mechanical and optical system to form simultaneous images of four equidistant portions of a circle on a film (H. Ritter, Z.f. Instrk. 55, 1, 1935).

The importance of the device lies in the great speed with which one is able to observe stars in declination; the device is specially tempting in climates with few clear nights.

In 1937 I tried whether the circles of the Leiden meridian instrument were good enough to be photographed. A picture was made through the visual microscope with an ordinary amateur camera. I obtained an image of the circle which was 17 times enlarged and which showed the divisions with sufficient clearness to be measured with a measuring engine. In 1938, during a short visit paid at Bergedorf, I had the opportunity to discuss the pros and cons of the photographic apparatus with Dr Larink, who laid great stress on the disadvantages which I will discuss in section 5 of this note. We wish to thank Professor R. Schorr for kindly lending us the Bergedorf drawings. It was not until 1940 that I was able to have the visual microscopes replaced by a photographic equipment. The construction was carried out by Mr Zunderman in the workshop of the observatory. The equipment has been made somewhat different from the Bergedorf instrument such as to meet our circumstances. In section 2 a short description is given, in section 3 the reduction is outlined and under 4 some of the results hitherto obtained will be discussed.

2. Figure 1 shows a part of the divided circle c and part of the photographic equipment attached to the pillar. A similar apparatus is placed diametrically at the other side of the pillar. At O an objective — "trioplan" — from an ordinary camera with a focal length of about 108 mm is mounted at a distance of nearly 140 mm from the circle. A lamp (6 V, 12 W) is fitted at L. A condensor focusses the light on a piece of ground glass put very near to the circle and which gives a fine indirect illumination. An attempt to use reflected light instead of scattered light ended in a complete failure, the cause of which was already understood and described by Kaiser in Leiden Annals 1, LXXII, 1868. At D a filmbox can be fixed to the end of the tube T. The box, Figure 2, contains 5 m diapositive film from Gevaert, 35 mm wide. The axis x carries two toothed wheels W and is connected with the oscillating electro-magnet housed in A, which is partly seen in Figure 3. An endless string connects...
Figure 3.

The necessary index on the film is formed by the shadow cast upon the film by a needle (later replaced by an X-shaped line-figure on a thin photographic plate) which is fitted at the end of T. When the filmbox is brought into its position and the shutter opened (Figure 4), this needle can be shifted very near to the film so that the shadow casted forms a sharply contoured figure.

The observation consists now in the following three operations: a) the telescope is set on the star; b) a knob is pressed for about 1.5 sec, during which time the lamp burns and the film is exposed; c) a second knob is slightly pressed three times in succession. At each pression the oscillating electro-magnet comes into action, which turns the axis x over such an angle that the film is moved 3 mm. The image on the film is 7½ mm wide, so the different images are formed with small interspaces. The time necessary to perform operations b) and c) is about 5 seconds and the observer is ready to pass on to another observation.

Figure 5 gives a scheme of one picture on the film. The circle bears only the units of the division in degrees. The position within a degree is seen from the length of the divisions. It was first deemed advisable to use two indices. They were placed at a distance of about 5 mm. The divided circle has a diameter of 98 cm and the divisions are 5’ apart. The enlargement given by the optical system is nearly 3 times, which means that the linear distance of two divisions on the film is about 2’2 mm. Any index is therefore always surrounded by other divisions than the second index.

Figure 5.

No special precautions were taken in the process of developing and drying of the film. The films were measured with an engine of the Gaertner type. As its screw shows a large periodic error, two wires are always used in measuring each object; the wires are ¼ revolution apart for the enlargement in use (30×).

3. Each star has been observed twice during the same night. The operations a)–c) were therefore performed twice for each star, yielding two nearly identical pictures on both films. The films will be denoted by A and B, the two exposures by I and II and the two indices by 1 and 2.

I pointed with the measuring engine on the two indices and on the divisions surrounding them immediately. The fraction n/d in which a distance between the divisions was divided by the index was computed. Each index on each film yields a reading of the circle of the form $p^a + q^b + r^c/d$, $p$ and $q$ being integers. The mean of these expressions for the corresponding indices on the two films is called $P$.

In this procedure the scale is computed from each measured distance $d$. In adopting this distance to be equivalent to $30^o$, the influence of the division errors is neglected. We do not know the division errors for each division separately, only the errors of the diameters formed by two opposite divisions. Therefore, the mean values $P$ were corrected for these diameter-errors by adding the term: $n\times(\text{differences of the two}$
diameter-corrections)/d. These corrected values will be denoted by $P_d$.

The result of one exposure is the mean of $P_1$, $P_2$, and $P_3$; this will be called $P$. The readings of each exposure were reduced to the reading corresponding to the meridian passage by applying the corrections for inclination of the horizontal wire and for curvature of the parallel; the values become then respectively $Q_1$, $Q_2$, and $Q$. These last values for the two exposures are averaged to get the result of one night.

4. I now pass on to discuss the accuracy obtained. I computed the mean error of one pointing from the pointings made with the two wires of the measuring engine. I assumed thus that the distance between these wires was a constant during one series of measurements. The following results were found (the numbers between parentheses denote always the number of observations used):

| on a division | m.e. $\pm 1.7\mu$ (384) |
| on an index   | $\pm 1.3\mu$ (388)      |

It may be argued that the mean errors thus obtained will be too small as the pointings with the two wires are made immediately after each other. However, they agree with the mean errors computed from measurements which are performed to find the sharp focus position, for which this objection is not valid. I adopt as the m.e. of one pointing irrespective on what object $\pm 1.7\mu$; all further computations are based on the mean of two pointings being treated as one, thus with a m.e. of $\pm 1.2\mu$.

The m.e. of any measured distance should then be $\pm 1.7\mu$. I have computed the mean error for a distance on the film by comparing the corresponding distances on the two consecutive exposures I and II. I made use of the different distances which could be computed from the different settings on divisions and indices. I must mention here that the enlargement with apparatus B is slightly more than with A so that the different intervals on the two films differ somewhat; this explains the many intervals given in the following table.

| interval in mm | mean error $\mu$ | excess over m.e. expected $\mu$ |
|               |                 |                                |
| 2.2           | $\pm 1.8\mu$    | $\pm 0.6\mu$ (696)            |
| 2.5           | $\pm 2.0\mu$    | $\pm 1.05\mu$ (696)          |
| 5.0           | $\pm 2.25\mu$   | $\pm 1.5\mu$ (444)           |
| 5.8           | $\pm 2.2\mu$    | $\pm 1.4\mu$ (442)           |
| 6.5           | $\pm 2.5\mu$    | $\pm 1.8\mu$ (378)           |
| 7.6           | $\pm 3.1\mu$    | $\pm 2.6\mu$ (378)           |
| 8.6           | $\pm 2.6\mu$    | $\pm 2.0\mu$ (188)           |
| 10.2          | $\pm 3.3\mu$    | $\pm 2.8\mu$ (188)           |

When we draw a graph with the width of the interval and the excesses over the expected m.e. as co-ordinates we find a sloping line. I can find no other explanation than the increasing influence of film distortion with increasing width of the intervals. Furthermore, the first line of this table is a good proof that the adopted m.e. of one setting of $\pm 1.7\mu$ can not be far wrong.

The mean error of the measured position of the index depends on the m.e. of $n/d$. If we assume an arbitrary zero point from which we count the distances of the index and the divisions (see Figure 5), then the m.e. $\epsilon$ of $n/d$ is given by

$$
\epsilon = \frac{(x_3-x_1)^2 + (x_2-x_1)^2 + (x_1-x_3)^2}{(x_1-x_3)^4} \epsilon_o \pm \epsilon_o
$$

$\epsilon_o$ denotes here the mean error, $\pm 1.2\mu$, of the mean of the two settings on each object. The maximum and minimum values of $\epsilon$ are resp. $\pm 0.00077\mu$ and $\pm 0.00067\mu$. The maximum and minimum mean errors of the position of the index are the values above multiplied by 300°. The numbers $\pm 0.23\mu$ and $\pm 0.20\mu$ differ so little that I will assume the first as the mean error to be expected for one measured position of the index. For the mean of two corresponding indices on the films A and B, thus for $P_1$ or $P_2$, this m.e. becomes $\pm 0.16\mu$. From the final values of the corresponding exposures I and II, a mean error of a complete observation may be computed. This m.e. comprises the m.e. of the setting of the telescope on the star and the influence of a wrongly adopted value of the inclination of the horizontal wire. The m.e. may be computed from the differences of the values $Q_1,\epsilon$ and $Q_2,\epsilon$ or from their mean $Q$ of the two exposures.

The m.e. of the final results was found to be $\pm 0.36\mu$ (566). The m.e. based upon the measurement of one index only per exposure was found to be $\pm 0.38\mu$ (1132).

From the value $\pm 0.16\mu$ of the expected m.e. of a position of one index and from the value $\pm 0.38\mu$ of the m.e. of one complete observation based upon the measurement of only one index, we may compute the m.e. of a complete observation when two indices are measured. This last value should be $\pm 0.36\mu$, where we did find $\pm 0.36\mu$, thus in good agreement. These results prove that the film distortion mentioned above seem to have had little influence on the final accuracy and furthermore, that it is unnecessary to measure two indices per exposure. It will be better to observe the star three times as the bulk of the mean error of a complete observation arises from the setting on the star; a value of $\pm 0.34\mu$ is found for the m.e. for the latter operation. The results seem satisfactory when we compare them with the mean.
error derived in Leiden Ann. XV, 27, 1927, where Hins
gives $\pm 0'.4^2$ as the m.e. of the pointing of the star
on the thread and of the readings of the two micro-
copes; this value is the mean for three different
observers. We may conclude that, with a m.e. of
$\pm 0'.38$ found above, the photographic method can
compete with the visual one. Finally, the admissibility
of applying division errors which have been deter-
mined visually on the photographic positions may
be discussed. The distances of the two indices,
measured in arc on one observing night, may be
intercompared, and a m.e. of this distance can be
computed in the case that the corrections for division
errors are applied or not. In the first case the m.e.
of one distance was found to be $\pm 0'.32$ (277), in
the second case this value became $\pm 0'.48$ (277).
There seems to be no reason to hesitate to adopt
these corrections.

5. Resuming, I may state that the photographic
method shows the considerable advantage of enabling
one observer to observe stars in declination with a
speed of one star per 45 to 50 seconds. It took me
2½ to 3 minutes to do so visually. The accuracy is
surely not less than with the visual method. The
mechanical and optical parts are simple and inex-
penensive. I never encountered a failure of the record-
ings due to meteorological circumstances. No special
precaution in keeping the circle clean has been
necessary up till now, after 9 months' use.

Now, something may be said about the time-
consuming factor after the observing night is over.
First, there is the development of the film. Secondly,
the film has to be measured. It took me 120 minutes
to measure the complete observations of 7 stars,
thus comprising 28 exposures, with the measurement
of two indices on each of them. Surely, this time
could be diminished by 30% if an engine were
available without a periodic error in the screw. The
factor of nearly $\frac{1}{2}$ may be applied when only one
index is measured, as will be done in future. The
computation of the readings to that state which makes
them comparable with the readings of a visual
microscope took us about 135 minutes per 7 stars
(again with both indices involved). With one index,
this amount will be halved. In the latter case we still
need somewhat over 2 hours to bring observations
of 7 stars to the state wherein an observer with
visual microscopes hands over his notes. As the num-
ber of stars observed in a year is considerably increased
as compared with the visual method, the arrears in the
reductions accumulate immensely. Still I believe that
the method is worth while in a bad observing climate.

I have been materially aided in the reductions by
Mr L. Gaykema. Mr H. Kleibrink has made the
pictures for this note.

Note added in proof:

In order to reduce the time factor still more, a measuring apparatus is being constructed, at the request
of Prof. Oort, such as to read at once seconds of arc. The only difference with the old visual method exists
then in the added measurement of the index and subsequent subtraction of this reading from the other
readings, as this quantity does not enter into the visual measurements of a circle.

Correction to B.A.N. No. 316, by G. van Herk.

Dr J. Woltjer has pointed out to me that the explanation of the change in azimuthal difference between
the northern and southern mires, given on page 315, is incorrect. My statement given there is incomplete.
The lenses which allow the rays coming from the mires to become parallel are cemented on pillars; these
pillars form with those on which the meridian instrument rests one solid block. The offered explanation
should therefore be “an east-west movement of this block” and not, as was given, “an east-west movement
of the meridian instrument”.

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