The Repsold meridian circle at Lund Observatory - Part II

In a previous document, dated 20 March 2006, I described the early history of the Repsold meridian circle at Lund Observatory and its fate after the department of astronomy was moved to the new Astronomy building in 2001. It briefly mentioned the attempts to modernise the instrument in the 1950s and 60s in particular replacing the original visual micrometer by a photographic micrometer. This second part gives more details on these developments, mainly based on the following documents:

1. Anders Reiz: *A photographic time recorder. With an appendix by L. Stigmark*, Arkiv för Astronomi, Vol. 1, pp. 199-205, (1950), available through ADS as https://articles.adsabs.harvard.edu/pdf/1950MeLuF.174....1R
2. Anders Reiz: *Meridian Observations of Faint AG Stars: Observations Made with the Repsold Meridian Circle of the Lund Observatory During the Years 1943-45 and Reduced to the Equinox of 1950. Description of Findings*, Annals of the Observatory of Lund, Vol. 11, pp.1-13 (1951), available through ADS as https://ui.adsabs.harvard.edu/abs/1951AnLun..11....1R
3. Nils Hansson: *Äldre och nyare meridianastronomi* (*Older and newer meridian astronomy*), Populär Astronomisk Tidskrift, Vol. XL (1959), pp. 48-61 (in Swedish)
4. Anders Reiz & Nils Hansson, in Transactions of the IAU, Vol. 10 (1960), pp. 119, 120, and 135-136, available through Cambridge University Press https://www.cambridge.org/core/journals/transactions-of-the-international-astronomical-union/article/8-commission-de-lastronomie-meridienne/89718F15A84B552AAA09685A45173A5A
5. Nils Hansson: *Investigations of the stability of transit circles. I. Thermal influence and mechanical flexure*, Arkiv för Astronomi, Vol. 3, pp. 137-154 (1963), available through ADS as https://articles.adsabs.harvard.edu/pdf/1966ArA.....3..137H
6. Nils-Eric Cerne: *En begränsad bestämning av delningsfelen på Lunds meridiancirkels deklinationsskala* (*A limited determination of the division errors of the declination circle of the Lund meridian circle*), thesis for the degree of licentiate, Lund 1966 (unpublished, in Swedish)

The major series of observations made with the Lund meridian circle are summarised in the table below. They were all made with the original visual micrometer by tapping a telegraph key when the star was occulted by the fixed vertical wires. For reading the declination scale, four microscopes were used in the first series, but from 1920 only two microscopes owing to some damage on the declination scale.

Observers (programme)	Year	No. stars	No. obs.	σ_α (s)	σ_δ (")
Lindstedt-Dunér-Engström (AGK1)	1878-93	11446	35413	0.083	0.76
Gyllenberg-Ohlsson-Ambolt (AGK2)	1920-26	11800	25557	0.046	0.55
Reiz (faint AG stars)	1943-45	6099	17173	0.036	0.54

Not listed in the table are some smaller series, e.g. by Frida Palmér (96 long-period variables observed 1933-35) and Reiz (480 fundamental stars observed 1943-45).

By the time when Reiz made his observations, the impersonal (travelling-wire) micrometer was in general use at other observatories. This avoids the "personal equation" in the visual registration of the transit times, that is the observer's characteristic reaction time, which appears as magnitude-dependent systematics in the right ascensions. While the technique used in Lund could thus be considered obsolete at the time, it gave Reiz the opportunity to study the (i.e., his) personal equation in some detail through a comparison with other catalogues [2]. (Walter Fricke once remarked that he much appreciated Reiz' study because it helped to understand the systematics in right ascension in the old observations form other observatories. According to Reiz, many of the old observations were overcorrected for the effect.)

Attempts to modernise the meridian circle in the first half of the 20th century had been unsuccessful for lack of funding. According to Reiz, "efforts were made to acquire a travelling wire micrometer and equipment for photographic recording of the declinations but owing to the war these efforts were without success." As early as 1930 the newly appointed professor of astronomy, Knut Lundmark, argued, in a petition to the Faculty of Science, that it was necessary to acquire an impersonal micrometer, new microscopes, and a new chronograph. Of these only the chronograph could actually be acquired.

Efforts towards a modernisation were renewed after the war. In 1950 Reiz [1] wrote: "When performing meridian observations during the years 1943-45 the present writer was lead to consider the construction of a device for recording the times of transit of the stars based on new principles." The result was an apparatus consisting of an electric clock (Fig. 1) driven by a quartz crystal oscillator, a photographic camera, and an electronic high-intensity flash-tube triggered by the observer.

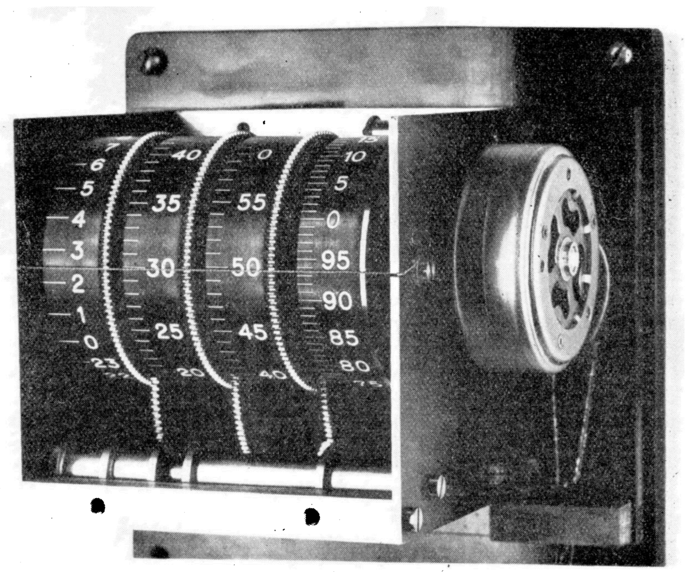


Figure 1. The electric clock without the cover (1950). The four wheels recorded sidereal hours, minutes, seconds, and hundredths of a second.

Because successive transits across the wires in the micrometer occurred at intervals of about 2 sec, it was not possible to use commercial flash lights which required much longer time to recharge. A special circuit, designed by Lennart Stigmark at the Department of Physics in Lund (later professor in applied electronics at the Faculty of Engineering) provided a recovery time of only 0.5 sec (see the appendix in [1]). From the photographic images of the clock wheels it was possible to read the time with an accuracy of about 0.002 sec. The clock correction was (at least later) determined by triggering the flash light with a radio time signal.

While this photographic device made the time recording much less laborious than the manual measurement of the chronographic paper tapes, it was not possible to benefit significantly from the accurate clock readings as long as they were used together with the old-fashioned fixed-wire micrometer: "When judging the value of the new technique as compared with the old one it must be kept in mind that no sudden increase in the accuracy of the observed right ascensions should be expected as long as the original technique in determining the transits across the wires is used. For the accidental errors in *determining* these moments exceed appreciably the errors made in *recording* them. [..] First when applying the unit in conjunction with photoelectric registrations of the transits the photographic procedure will show its real superiority to the old technique."

Clearly, around 1950 Reiz had in mind to attach a *photoelectric* micrometer to the meridian circle. Experiments with photoelectric recording of the transits were indeed carried out in the first half of the 1950s by Reiz and Hansson. I have found no published account of these experiments except in the popular paper by Hansson [3]. After describing the principle of the travelling-wire micrometer, he writes:

"In recent decades there have been attempts to make the transit determination completely impersonal by photoelectric means; but such devices are not as simple as one might think. It could be imagined that it is only a matter of putting a photocell behind a number of coarse slits in the focal plane of the meridian circle, and feed the impulses from the photocell to a suitable time registration apparatus, but it is not that simple. The unsteady atmosphere or the scintillation of stars causes a large number of false impulses when the star passes by the openings in the field of view. [...]
In Lund attempts have been made with a different type of registration using a photocell."

(my translation). From this text it looks like a photoelectric slit micrometer was not seriously considered in Lund owing to the anticipated problems with scintillation, but according to Cerne [6], a test with "a grating and photocell" was actually made in 1953. I believe this statement from 1966 must be correct: Hansson surely scrutinised Cerne's thesis and was probably the source of the information in the first place. In this test the amplified signal from the photocell was probably connected more or less directly to the previously described "photochronograph" for photographic time registration. Because the latter had a recovery time of about 0.5 sec, the registration would be triggered by the first impulse created by the star on each slit, resulting in time determinations that were very uncertain and highly sensitive to atmospheric effects. Apparently the test was so unsuccessful that Hansson did not find it necessary to mention it in his popular account.

The "different type of registration" mentioned by Hansson [3] employed two photocells, a reflecting roof prism to bisect the stellar image, a motor-driven screw moving the prism, and an electronic feedback system to control the motion (Fig. 2).

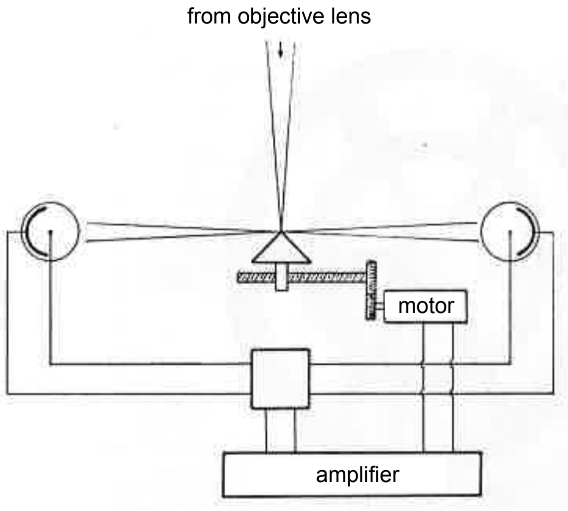


Figure 2. Schematic illustration of a photoelectric micrometer (adapted from [3]).

The purpose of the photocells was to adjust the speed of the prism in such a way that the light from the star was always split in two equal halves. Attached to the screw were electrical switches that activated the time registration much like in a travelling-wire micrometer. The frequency of the alternating current driving the motor was automatically adjusted according to the difference in the intensity of the light at the two photocells. The alternating current driving the motor was obtained as the beat frequency between a fixed oscillator operating at 10 050 Hz and a second oscillator with a frequency around 10 000 Hz that was regulated by the intensity difference. In this way the prism was forced to follow the star.

In a footnote to this description Hansson remarks: "The idea for this method, as well as the principles of several other devices used at the Lund meridian circle (for example the previously mentioned photochronograph) was put forward by Professor A. Reiz in Copenhagen. The equipment was built and tested by Professor Reiz in collaboration with the writer."

No details are given about the performance of the photoelectric micrometer, except a statement that it "worked well". I have never seen any parts of it preserved at the observatory, and suspect that only an experimental prototype was made and parts of it perhaps re-used in other experiments. There are several things I would have liked to know more about - for example whether the speed at equal intensity was adjusted according to the declination of the star, and the amplifier gain according to its magnitude.

In 1955 Lund Observatory was asked to participate in the observation of AGK3R (the reference stars for the photographic AGK3 catalogue). This would require more accurate observations than had been obtained in the earlier AGK programmes with this instrument. Activities towards this end started in 1956 and involved a major overhaul and improvement of the various parts of the meridian circle. The work was lead by Reiz and Hansson and the detailed mechanical design and construction work was done by Egon Olsen. The replacement of the damaged declination scale by a new one in gold, divided at the U.S. Naval observatory, was part of this renovation.

The photoelectric micrometer described above could only determine right ascensions. For AGK3R it was mandatory to measure declinations as well, for which the photoelectric method could not easily be adapted. The photoelectric method was therefore abandoned in 1955 in favour of a *photographic* micrometer, which had to be designed from scratch. Some 30 detailed construction drawings by Egon Olsen are preserved in our archive; they span the time interval from August 1957 to April 1962. A partial scan of one of the drawings from 1959 (Fig. 3) gives an impression of the complexity of the work and the great attention to detail. Olsen had a permanent position at the Observatory as "instrument maker" at least from 1958 until his retirement in 1986. A large number of drawings of the electronic control circuits have also been preserved.

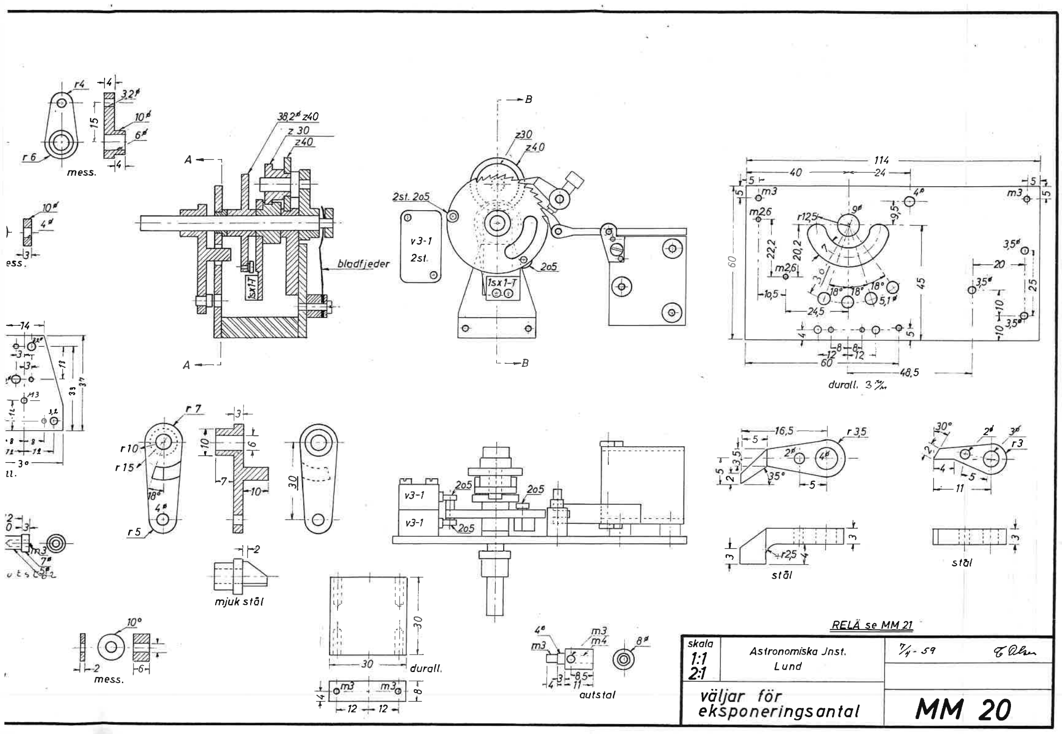


Figure 3. Example of a construction drawing by E. Olsen for the photographic micrometer (detail). This is the mechanism for choosing the number of exposures taken per field-of-view transit.

Reiz and Hansson reported on the ongoing work to Commission 8 (Astronomie meridienne) at the IAU General Assembly in Moscow 1958 [4]. In the triannual report for 1955-57 they write (p. 119) "The observational work at the Lund Observatory has been interrupted since 1955 for a thorough reorganization of the meridian department. It is expected that regular observations of AGK 3R stars will begin early in 1958." This appears to have been very over-optimistic. On p. 120 (probably reported at the meeting in August 1958): "At Lund the work on meridian astronomy has now been thoroughly reorganized. The Repsold meridian circle has been completely overhauled. A new time service based on the quartz clock at the Physics Institute is in regular operation. The electronic computer at the Theoretical Physics Division is used for the reduction of the observations." The photographic micrometer is described on pp. 135-136, here quoted in extenso:

"6. *A photographic impersonal transit-circle micrometer* (A. Reiz, now at the Copenhagen Observatory, Denmark, and N. Hanson). The impersonal character of the photographic micrometer, built for the renovated Repsold meridian circle of the Lund Observatory, has been achieved by removing the observer from the eyepiece end and placing a photographic plate in the focal plane of the transit circle, which thus has been converted from a visual to a photographic astrometric instrument. The compensation for the diurnal motion during a short exposure, 15-20 sec, say, has been accomplished in the following way: the stellar image is kept stationary with respect to the photographic plate by introducing, in front of this, a plane parallel glass plate, which is brought to rotate round an axis parallel with the meridian plane, and normal to the collimation axis. By adjusting the rotational speed of the glass plate according to the declination of the star, the stellar image is displaced with the proper speed so as to compensate for the diurnal motion. This technique has been developed for the Lund meridian circle; it has also been applied by W. Markowitz *(Astr. J.* 59, 69, 1954) in his dual-rate Moon camera for holding the Moon fixed relative to the stars during exposure, and has further been suggested by Y. Väisälä *(Astronomisch-Optisches Forschungsinstitut der Universitat Turku,* 1955) for similar purposes.

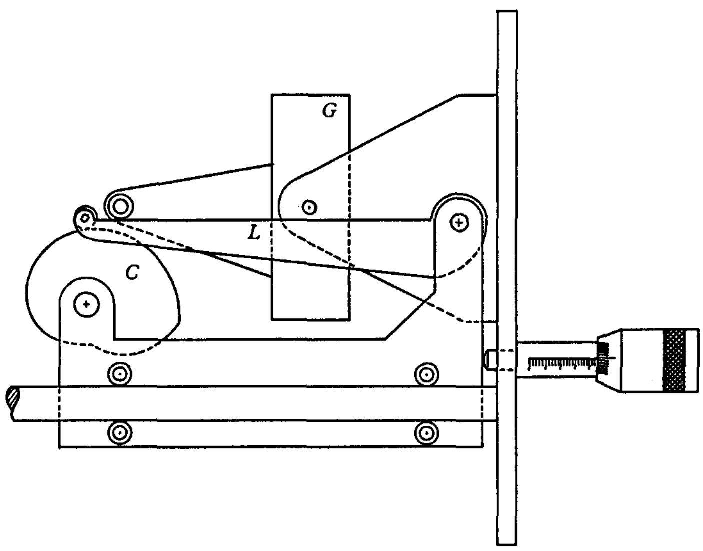


Fig. 2

With the new micrometer the observations are performed diametrically different to the classical transit observations. Instead of recording the moments of the moving star's transits across the vertical wires, one keeps by means of the slowly rotating glass plate the stellar image fixed on the photographic plate, and by means of a graticule in near contact with the emulsion, time marks can be impressed at certain pre-selected positions of the glass plate. The position of the star can then be defined relative to these marks. Three to five independent exposures, each of about 17 sec duration, will be made, and the reference line will be impressed at the instant the glass plate is normal to the collimation axis. This moment can be determined with an accuracy of a few milliseconds.

The collimating error is determined in the following way. The collimator slits, about 20 µm wide, in the north and south collimator telescopes are photo-electrically adjusted for coincidence, and the transit circle directed towards the collimators and the slits photographed with the glass plate in its zero or normal position.

The construction of the micrometer is indicated in Fig. 2. The rotation of the cam *C* (operated by a synchronous motor from a frequency of high stability) is transmitted to the glass plate *G* via the lever *L.* In order to make possible variation in the rotational movement, that is for covering a sufficiently wide declination zone, the cam *C* and lever *L,* which are fixed relative to each other, can be displaced along a slide. This movement is accomplished by means of the micrometer screw, visible to the right in the figure. The cam C has been shaped so that for one revolution the lever *L* is moved from one extreme position to the other, in 17 sec, after which time the glass plate is brought back to its starting position.

On the basis of observations of a number of FK stars, carried out over four nights, we have tried to form a preliminary estimate of the accuracy of the micrometer. The external probable error for one night for a time determination is close to 10 milliseconds, or about the same accuracy as for photo-electric registration *(Report* of Commission 31, p. 488). It is likely that with the introduction of definitive arrangements, an improvement in accuracy should be feasible.

Exposures of 17 sec length with Ilford HP 3 plates have yielded well-measurable images of stars of visual brightness 9.5-9.7 mag."

From the above reports made in 1958 it sounds like the micrometer was practically ready for the AGK3R observations. But that was hardly the case, as many construction drawings for the micrometer are dated several years later.

Figure 4 is a picture of the micrometer copied from [3] and therefore probably taken in 1958 or 1959. Figure 5 shows pictures taken by me in March 2023. The demounted micrometer (currently stored in the optics lab of the Astrometry building) is fixed to an aluminium ring that can be rotated about two pivots in a wooden frame. Comparing the two figures it can be seen that many details are different and essential parts are missing in the old picture, including the photographic plate holder (P), the synchronous motor (M) and the mechanism for adjusting the speed depending in the declination (D). From several differences, for example the mounting of the rotating glass plate (G), it appears that the old picture shows a prototype version that was much elaborated in subsequent years.

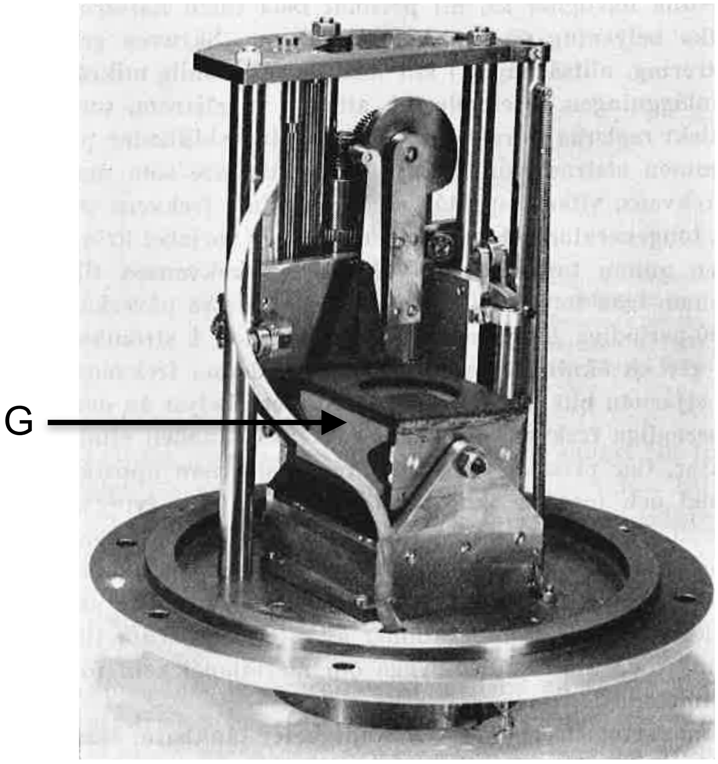


Figure 4. The photographic micrometer. G is
the rotating glass plate. (From [3], in 1959.)

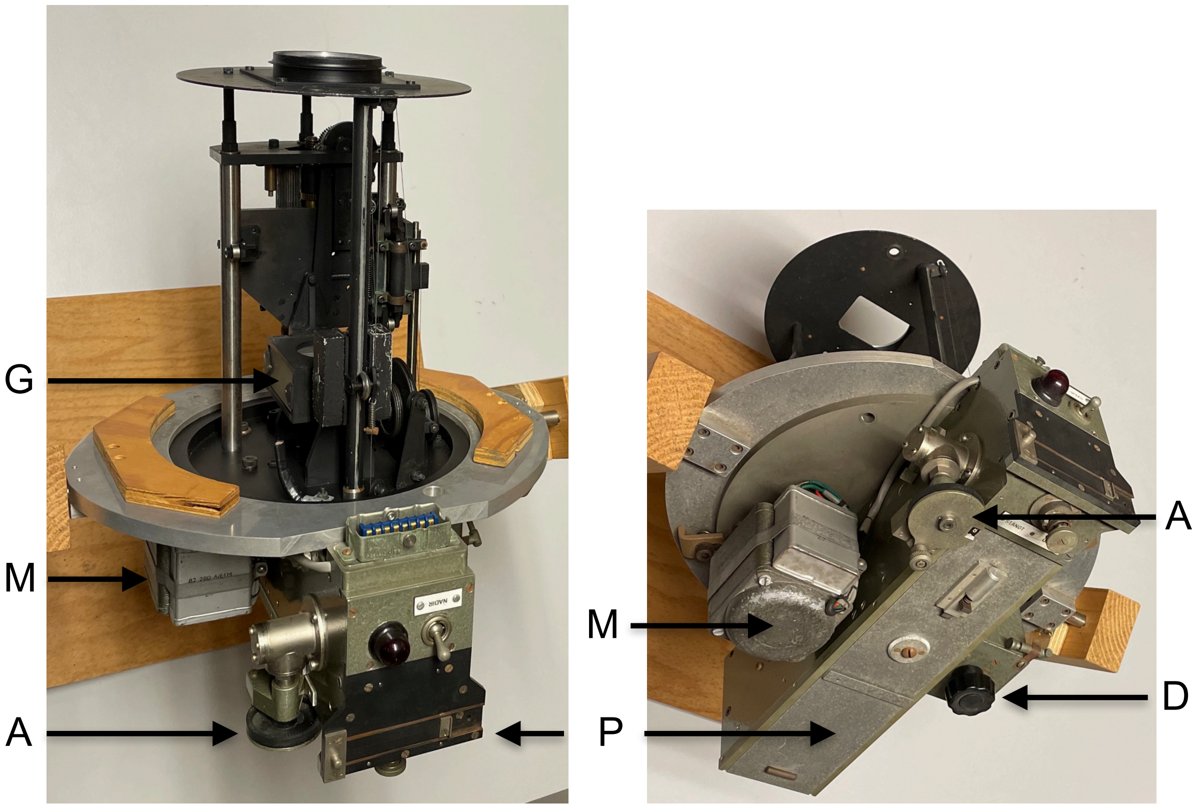
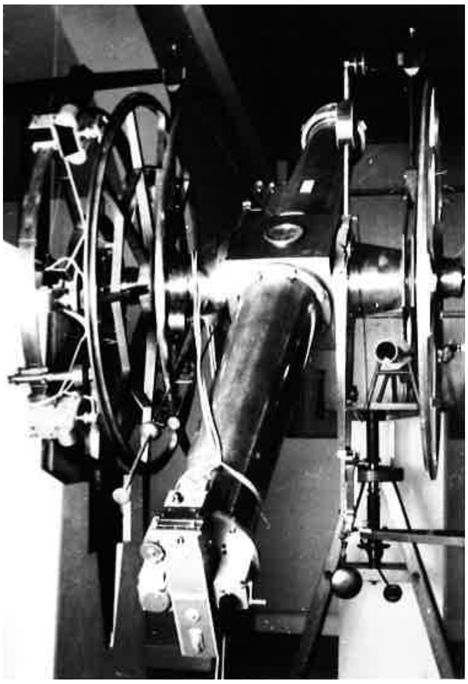


Figure 5. The photographic micrometer in its current state. Left: viewed from about the same angle as in Fig.4. Right: viewed from the back (observer's) side. G = glass plate compensating the diurnal motion, M = motor driving the glass plate, P = photographic plate holder, A = mechanism to advance the photographic plate for the next star, D = knob to set the rotation speed of the glass plate (G).

Another part of the modernisation concerned the declination readings. With the new declination scale in place 1956, a system for photographic registration was constructed [6]. This used six cameras for 35 mm film equipped with microphotography objectives of 24 mm focal length, manufactured by Leitz. The distance of the cameras from the circle was chosen to give a magnification of 2.5, so the 3' divisions were separated by about 1 mm on the film, giving a scale of 0.18 arcsec per μm. A glass plate in contact with the emulsion had an engraved line that provided the index against which the scale was read. The declination scale was illuminated by two small 6 V light bulbs on either side of the camera objective. The cameras did not have any shutters, and the exposures were taken by flashing the light bulbs for a fraction of a second. This had the additional advantage that the heating of the scale by the light bulbs was minimised. After the exposure the film was advanced by means of hooks acting directly on the perforated film. The advancement was made simultaneously in all six cameras by means of thin steel wires in helix housings connected to a central unit on one of the pillars. Care was taken to adjust the tension of the wires and of the return springs for smooth operation without mechanical shocks that could affect the stability of the cameras. The exposure and film advancement were triggered at the central time of transit, but could also be triggered manually e.g. for the determination of division errors. Figure 6 shows an overview of the instrument with the cameras in place, and a close-up of a camera with the cover removed.



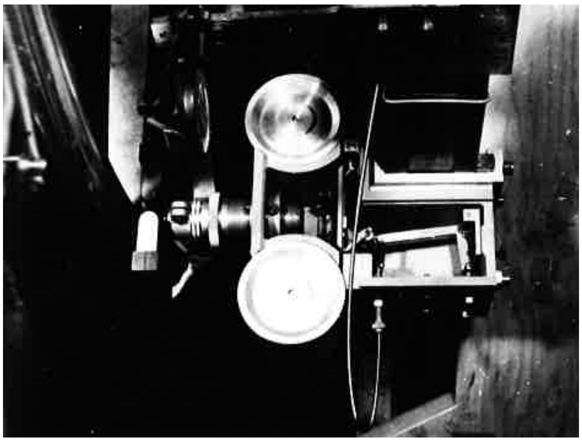


Figure 6. Overview of the instrument in 1966 and a close-up on one camera [6].

Using cameras to register the declination readings greatly simplified the observations which could now even be done by a single person - in the earlier observations at least two assistants were needed to read the microscopes. It also removed many heat sources from the vicinity of the instrument, and provided a permanent record of the readings which could be measured, and re-measured if needed, under more optimal conditions.

The intention was that also the measurement of the declination films should be automated. In his description from 1959 Hansson [3] writes: "The films [...] are measured in a fully automated apparatus according to Watts' method. This device is constructed according to the principle that the image of the line is photoelectrically balanced over a prism roof, and when balance was achieved between the two photocells the device is moved to the next division line, where another balancing is done by the apparatus. When this is finished, the micrometer readings [of the prism positions?] are photographed and the film advanced for the next measurement." If such an apparatus was ever tested in Lund, it might have re-used the roof prism and other parts from the abandoned photoelectric micrometer in Fig. 2. However, Hansson goes on to describe a different kind of apparatus, under development at Pulkovo Observatory, in which the film or the actual declination scale is continuously scanned by a device driven by a synchronous motor. Cycles of the alternating current driving the motor are counted by electronic counters that are started and stopped at the precise moments when the scanning device is centred on a division or index line. In this way an accurate digital reading of the distances is obtained. The principle is rather similar to the measuring apparatus actually built in Lund several years later (see below).

The modernisation of the Repsold meridian circle included several more elements in particular for the determination and monitoring of the azimuth, inclination and collimation errors, and the nadir position, which are not described here.

In 1958 Anders Reiz became a full professor in Copenhagen and director of the university observatories in Copenhagen and Brorfelde. This must have been a serious blow to the modernisation plans for the meridian circle in Lund. However, given the limited manpower and funds available for the project, these plans had probably never been very realistic. Also, the overall direction of research at Lund Observatory was changing in a more astrophysical direction with the appointment in 1955 of Carl Schalén as the new director after Lundmark, the opening of the observing station at Jävan with a 60 cm reflector for photoelectric UBV observations, and the beginnings of ESO. Nevertheless Hansson continued to work on the meridian circle for at least five more years [5], more or less alone although apparently with considerable support from the workshop. In the end Lund Observatory did not contribute to AGK3R, which was completed in 1963.

In the licentiate work by Nils-Eric Cerne from 1966, the photographic registration of declination readings was used for a limited determination of division errors according to the method described by Erik Høg (*Astron. Nachr.* 286, 65, 1961). Declination measurements are always made by averaging the readings in pairs of diametrically positioned micrometers, so for a circle with 3' divisions there are a total of 3600 diameters for which division errors need to be determined. However, Cerne's investigation was limited to the determination of a group of 45 equidistant diameters. This was done using three pairs of microscopes (cameras) positioned at 0, 36, and 88 degrees angle from an arbitrary origin. Cerne corresponded with Høg, who advised on the use of the method and choice of angles, and also provided the numerical coefficients needed to compute the division errors from the measurements. The films with the 6 x 45 = 270 images were manually measured by Cerne in a comparator (probably of Abbe type) with an estimated uncertainty of about 1.7 µm or 0.3 arcsec per image. The resulting division errors, having a dispersion of about 0.6 arcsec, would then be obtained with a precision of about 0.17 arcsec per diameter.

Cerne remarks that a machine for automatic, impersonal measurement of the films was under construction in 1966, and expresses the hope that this could increase the accuracy of the declination readings by a factor 10. The device would produce the measurements on a punched tape for direct input to the electronic computer SMIL (*Siffermaskinen i Lund*), one of the first computers in Sweden, located at the Physics department and in operation from 1956 to 1970.

Around 1972 when the Lund meridian circle caught my interest, such an apparatus for the automatic measurement of declination films was actually standing in the clock room next to the meridian room in the old Observatory building. It was a tall (perhaps 1.7 m), free-standing rack with a lot of electronic and mechanical components. Unfortunately I have found no picture or drawing of it, and the machine itself was probably thrown out some years later. The following description is therefore entirely from my memory and may be inaccurate. The apparatus was designed as an exam work at the technical faculty, perhaps at Lennart Stigmark's department of applied electronics, but the mechanical parts were probably made at our workshop.

At the top of the rack was the film holder and an objective projecting a magnified image down to a device much like the photoelectric micrometer in Fig. 2, with two photocells, a reflecting roof prism, and a motor-driven screw. Attached to the screw was a steel disk with many teeth and an electromagnetic pickup, which generated a sequence of electric pulses fed to two electronic counters. When the prism was moved across the image, the difference between the two photocell signals went rapidly through zero at three instances: first, when the prism was centred on one of the division lines (bright on the negative film), second when it was centred on the index line, and third when it was centred on the next division line. At the first instance, both counters were started; at the second, one of the counters was stopped; and at the third, the other counter was stopped. The interpolated position could thus be obtained from the ratio of the two counters. Each counter had several registers counting from 0 to 9. After the scan was completed, these numbers were punched out in binary code on paper tape, five holes wide. I had the opportunity to test the apparatus on some of the existing films. In principle it worked, although I have no idea how accurate it was. Some of the electromechanical parts were quite unreliable - a stepping switch of the kind used in telephone exchanges was (if I remember correctly) used to convert the single-number counts to binary code, but it sometimes missed a step so that 555 could be coded as 545; also the tape punch was not of the best quality.

I was however intrigued by the declination measurements at the circle and attempted several improvements. For example, the illumination of the division lines by the light bulbs was quite unsatisfactory, and so I tested using optical fibres instead, which could more easily be adjusted for optimal illumination. I also re-analysed Cerne's measurements and introduced additional unknowns representing linear drifts of the camera positions and systematics from alignment errors of the cameras. Nothing useful came out of these experiments but I learned a lot about the instrument and about measuring technique in general. In particular Høg's method for the determination of division errors gave, a few years later, the impetus for the "great-circle reduction" step of the Hipparcos data analysis, and an analytical formula for the optimisation of the basic angle in Hipparcos and Gaia.

Written by L. Lindegren, Lund Observatory, 5-9 March 2023.