THE GLASS MERIDIAN CIRCLE

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ABSTRACT

Some aspects of the design for a Glass Meridian Circle with 24 cm aperture are presented and discussed. Tangential ventilation will be used to minimize tube refraction. The air for the ventilation will be filtered and it will provide a clean atmosphere around all optical and critical mechanical components, thus improving reliability. The base frame and piers are particularly stable thanks to a sharp separation between parts with short and long thermal time constants. The instrument is compact and portable and it requires only a small dome.

1. INTRODUCTION

The principles of the conventional meridian circle with its lens telescope fixed perpendicularly on the east-west axis have been remarkably adaptable to the on-going technical development since it was first built by Ole Rømer 280 years ago. Being improved by the best available manufacturing techniques the conventional meridian circle has remained the main instrument for absolute astrometric observations even to-day. Great efforts at a number of observatories through the past several decades to develop meridian circles with different kinds of reflective optics have not as yet given convincing results.

After photoelectric micrometers have reached the limit of accuracy set by atmospheric image motion, i.e. about 0.15 arcsec (rms) per transit observation, it has become more urgent to overcome the remaining error sources. These are believed to be connected with the long telescope tube and its mechanical flexure as function of zenith distance as well as asymmetric and variable thermal influences on the long tube. Refraction due to air in the tube also seems to be important, Høg (1986).

An advanced project of a horizontal mirror meridian circle has

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many years ago been realized at Pulkovo Observatory, and is presumably described in the paper by Gumerov and Pinigin (1986) to be printed in these Proceedings.

Another principle has been proposed under the name Glass Meridian Circle (GMC), Høg (1971 and 1974). Studies of the technological problems have been made since then at a pace given by limited available time and resources. The strategy has been to take sufficient time to study the problems before investing any large amount of money in manufacturing the instrument, lest one would be stuck with an instrument with faults that could be remedied only by even larger investments. The studies are now so advanced that the instrument can be built with full size aperture of 24 cm diameter. That this stage has been reached is for a large part due to the interest in the GMC shown in recent years by Chinese colleagues, notably Dr. Hu Ningsheng.

It is planned to build the main optical and mechanical parts in China and to test the instrument in Denmark at Brorfelde by means of visual michrometers. For the later operation in China the GMC will be equipped with photoelectric michrometers.

Some aspects of the design shall be discussed in the following.

2. OPTICAL AND MECHANICAL PRINCIPLES

The principle of the GMC is explained in Fig. 1 to which the following must be added.

The two concave mirrors S3 - S4 form a rigid unit. The optical direction or tilt of this unit is monitored by means of S4 having its center of curvature at the micrometer. A point source in the focus will obtain its image also in the focal plane where its position can be measured. Such measurements as function of zenith distance, furthermore, serve to determine the *translational* pivot errors of the bearing.

On the other hand the *rotational* pivot error or tilt of the bearing may not be a repeatable function of the zenith distance. This error may be determined at each observation of a star by means of autocollimation with three reflections onto S2: The point source in the focus will give a parallel beam by S3 which is reflected by S2 and again focussed by S3. The tilt of S2 can then be determined taking into account the tilt of S3 determined above.

Proper formulae for these reductions have been established.

2.1 Tangential Ventilation and Quick Autocollimation

It is important that the micrometer is capable of a quick autocollimation

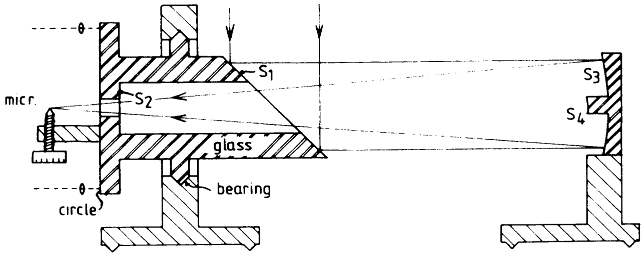

Fig. 1. Optical-mechanical principle of a Glass Meridian Circle. - Light is reflected from the inclined flat onto the concave mirror with focus at the micrometer. Glass cylinder with mirror and division circle is set in declination by rotation about the horizontal axis.

In the real planned GMC with 24 cm aperture the glass cylinder is replaced by a strong copper tube carrying the two plane mirrors S1 and S2 at each end

measurement on S2 even using the rather small annular aperture defined by the diameters of S4 and the hole in S1. Since it may be needed at every star it should not take more than say 4 seconds and give a precision better than 0".1 rms. Experiments with the CAMC slit micrometer (Høg, 1984) have shown that this is possible if the point source intensity is increased and if tangential ventilation of the tube is employed. Without such ventilation slow components of image motion would give larger rms errors and systematic errors.

Tangential ventilation will be used in the GMC telescope and in the collimator. The former telescope is a quasi-Schmidt telescope with a spherical mirror and a corrector plate in front of the inclined mirror (not shown in Figures 1 and 2). Tangential ventilation is only possible in such a closed optical system where the air will escape through the hole in S1 and through a central hole in S3 of 2 cm diameter (not shown).

The parabolic collimator telescope will be closed by a plane-parallel glass plate in front of the inclined mirror so that tangential ventilation can be used and, the parabolic mirror will have a central hole.

The air used for ventilation will pass through a microfilter. This very clean air will surround all mirrors in the GMC and the collimator, the stellar micrometer, the circle and micrometers, main bearings etc.

This cleanliness should improve reliability and precision of the components and thus of the instrument.

2.2 Mirror Balancing

The strong copper tube, mentioned at Fig. 1, will ensure a constant angle between S1 and S2 mirrors, since a certain thermal flux from outside will give only small temperature differences in the tube due to its high thermal conductivity.

The weight of the S1 mirror will be balanced by two coaxial counter weights inside the copper tube lest the angle between mirror and copper tube shall depend on zenith distance.

A small flexure is still expected and it shall be calibrated by measurements on collimators, a zenith mirror and a nadir mirror.

2.3 Main Bearing

A unit of the following parts is rotated for setting in declination: micrometer, copper tube with mirrors, division circle, spur gear, and short tube with corrector plate, all mounted on a strong circular plate. This circular plate slides on five pads defining a horizontal axis while most of the weight (= 150 kg) is carried on a roller.

This bearing will, hopefully, prove to give rotational pivot errors being a repeatable function of zenith distance, at least during a night. In that case the autocollimation onto S2 need not be made at each star, but the error as function of zenith distance would be determined at the beginning of the night, and perhaps be repeated in the morning.

2.4 Base Frame, Piers, and Dome

The optical parts consisting of five mirrors of 24 cm useful aperture, Fig. 2a, are fixed in five adjustable mountings. These are placed on a base frame, Fig. 2b, built of steel I-beams (HE-profile, 100 A).

The frame is supported isostatically in four points defined by four concrete piers standing on the large pier on which the CAMC was standing in Brorfelde. The support is isostatic, i.e. it is rigid against rotation in azimuth but, differential expansion between frame and piers does not introduce a stress.

The frame temperature is close to that of ambient air. Since the time constant is 0.5 hour it will only lag 0.3 K if the air cools at 0.6 K/hour as on a typical night. A theoretical and experimental study has shown that this leads to an angular stability of azimuth direction and inclination of better than $0\overset{''}{.}1$ as far as the frame contributes to the instability.

The four small piers and the large one are insulated and thus obtain high stability because they do *not* follow air temperature. The time constant of the small piers is increased from 6 hours without

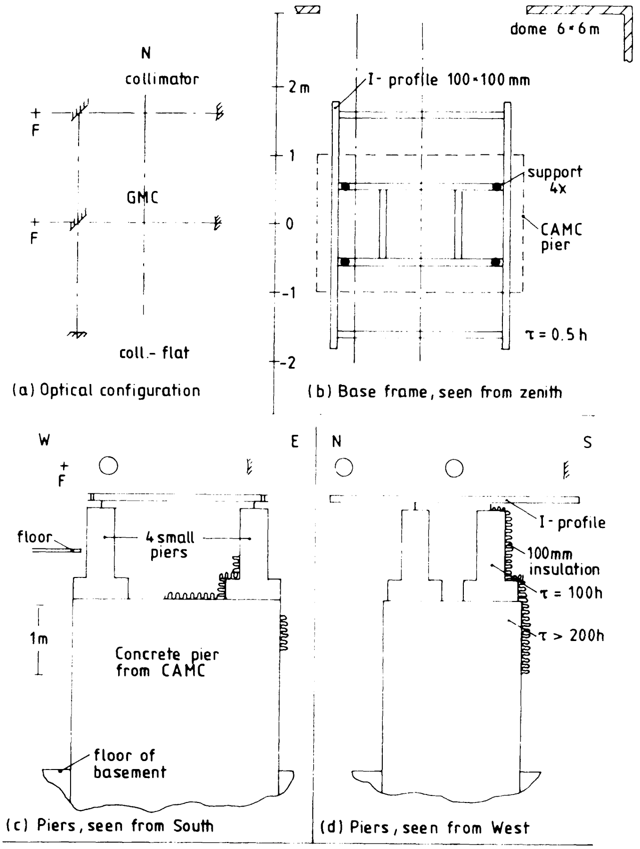

Fig. 2. Base frame and piers. -
(a) Optical configuration of GMC with a North-collimator telescope and a South-collimator flat.
(b) Base frame on which the optics is placed. The thermal exchange with air has a low time constant of 0.5 hour. The frame is supported isostatically in 4 points. A small dome 6 x 6m^2 is indicated at the top.
(c) and (d) 4 small piers stand on the large pier. Insulation increases the time constants from 6 and 30 hours to 50 and 250 hours, respectively, for the small and the large piers

insulation to 100 hours, and the effective time constant of the large pier is increased from about 10 hours to over 200 hours.

The optical mountings will follow air temperature within less than 1 K.

The sharp separation between parts following air temperature (base frame and above) and those not following air temperature (piers) will tend to give a good stability of azimuth and inclination.

Such a sharp separation is not found in a conventional meridian circle, cf. Høg (1978), and cannot be introduced due to the two piers in East and West. They cannot conveniently be very well insulated and they are too massive to follow the air temperature well if they are *not* insulated. This must be the main reason for the drift of 1 arcsec during the night of azimuth and inclination typically found on the meridian circles at Perth and at Brorfelde. Temperature gradients will build up in the piers depending on wind velocity and direction and on temperature difference with air. These variable horizontal and vertical gradients will change the direction of the East-West axis.

A smaller dome than the one in Brorfelde is indicated in Fig. 2b. If its inside is 6 x 6 m^2 there would be about one metre between instrument and wall on all sides. From floor to ceiling might be 3 m. This is much smaller than the Brorfelde dome being about 11 x 8 m^2 and more than 5 m tall - and the small dome would be many times cheaper to build. The dome slit should be wide enough, about 3 m, to permit observation with the reversed GMC. The reversal is done by moving the five mirror mountings individually, e.g. by a crane in a gantry.

3. ECONOMY AND RELIABILITY

The GMC is expected to give smaller accidental and systematic errors in observation of stellar positions than a conventional meridian cricle. The design study supports this expectation but, only observations with the full size instrument can give a proof.

It is, however, evident that the instrument will be more economic to build due to its compactness, less number of components and its simpler components. The dome will be much cheaper due to its smallness.

The instrument should be easier to maintain due to its compactness and the inherent cleanliness provided by the clean air ventilation. This should be a considerable advantage in a dusty climate.

The instrument, including base frame, may be packed in wooden boxes weighing altogether less than 3000 kg and the assembly is simple. The GMC is obviously a portable instrument while the conventional meridian circle is quite expensive to move from one site to another. To send the GMC from Copenhagen to Shanghai by ship would cost 400 US $.

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4. REFERENCES

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Discussion:

BILLAUD: What is the maximum estimated temperature difference between the isolated pier and the instrument?

HØG: A few degrees, but the difference between the temperatures of the base plate and the air will be 0°.3 or so.