DESIGN FOR A LARGE TRANSIT CIRCLE WITH REFLECTING OPTICS

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ABSTRACT

This paper describes a conceptual design for an automatic transit circle with Ritchey-Chretien Cassegrain type optics of 40 cm aperture. The instrument takes reversal observation both in the meridian and in the prime vertical. Methods of adopting active optics to achieve a stable boresight of the reflecting telescope and of automatically reversing and leveling the instrument are presented. The instrument can also be used in a theodolite mode.

1. **Introduction**

The purpose of the proposed transit circle is to make contributions to the absolute determination of star coordinates. Since we expect to use this instrument to observe also faint stars (of a least 13^{m}) the telescope aperture must be fairly large. We must choose Cassegrain type (i.e., Ritchey-Chretien or Schmidt-Cassegrain) reflecting optics for a telescope as large as 40 cm aperture with 5 m focal length because its tube is very short (only about a quarter of the focal length).

The background brightness near the star is a major obstacle to reaching fainter magnitudes by increasing the telescope aperture. It is therefore important to develop a micrometer that can reduce the detrimental effect of the background light to a tolerable amount.

Although a reflecting telescope is compact, its boresight (line of sight) is very unstable. For example, the catadioptric optics of the formerly planned Automatic Transit Circle of the U.S. Naval Observatory experienced serious trouble because of the unstable boresight (Westerhout and Voliden 1981, p. 449).

Another unique feature of our planned instrument is that it functions like a theodolite and can be reversed in the course of the observations; this facilitates the elimination of the collimation error, the zenith- point error and the zero-point shifts of the reading systems during each observation. If the upper, reversible part of the instrument is furthermore equipped with a suitable leveling servo system in both the N-S and E-W directions, the horizontal rotation axis will be kept level (both before and after reversal); this eliminates the inclination error of the axis and preserves the zero-point of the divided circle.

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When the instrument is reversed during the course of the observation, slow variations of a number of important characteristics of the instrument are all tolerable since these need be kept stable only for a comparatively short time span (one minute before and after reversal).

Wei Mao of the Yunnan Observatory proposed a unique method of observation, which determines not only the transit time and the meridian zenith distance of stars during their meridian transit, but also the time of their passage through the prime vertical. Mao's method allows one to determine the azimuth error without observing azimuth mires and thus to determine the absolute latitude of the instrument without observing circumpolar stars whose zenith distances are too large to be precisely determined at a site with a low lattiude (Mao et al. 1983). For such an instrument, the traditional accessories for a transit circle such as the N-S collimators, the nadir mirror and the azimuth would no longer serve a useful purpose.

2. The main parts of the instrument

1 - zenith distance driving system,

2 - divided circle,

3 - photoelectric leveling detecting device,

4 - fork assembly,

5 - leveling servo systems,

6 - rotary table.

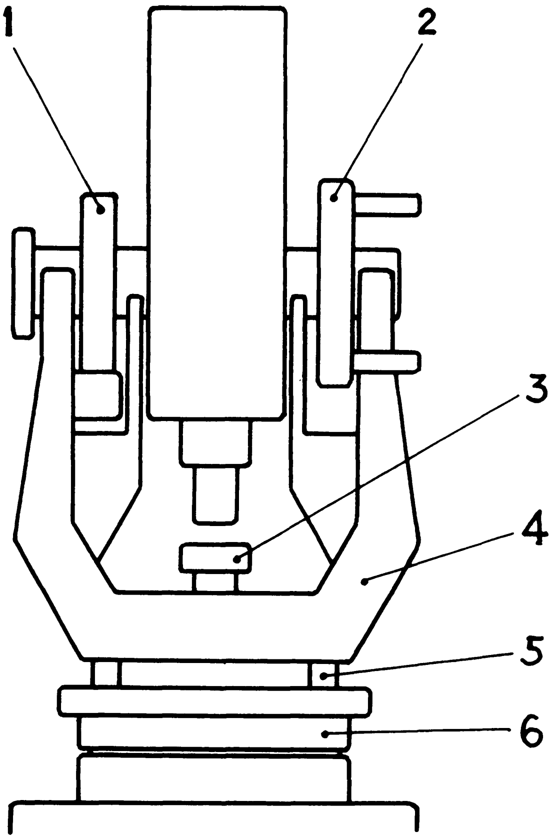

Fig.1 Main parts of the instrument

Some of the main parts of the instrument such as the horizontal axis with its bearings, the divided circle with its photoelectric reading microscopes, etc., are more or less similar to those of a traditional transit circle. We describe therefore only the unique features of our design.

2.1 The 180° reversal device

With the use of a pair of precisely plane multiple-teeth discs one can get very good angular repeatability up to 0″.02 for rotations of the upper disc by 180° with respect to the lower (cf. Fig.2). By connecting the upper disc to the rotating table and the lower to the instrument base, an electric driving mechanism can be exactly reversed in the course of each observation. The entire process (including leveling and setting the telescope) is programmed to last twenty seconds.

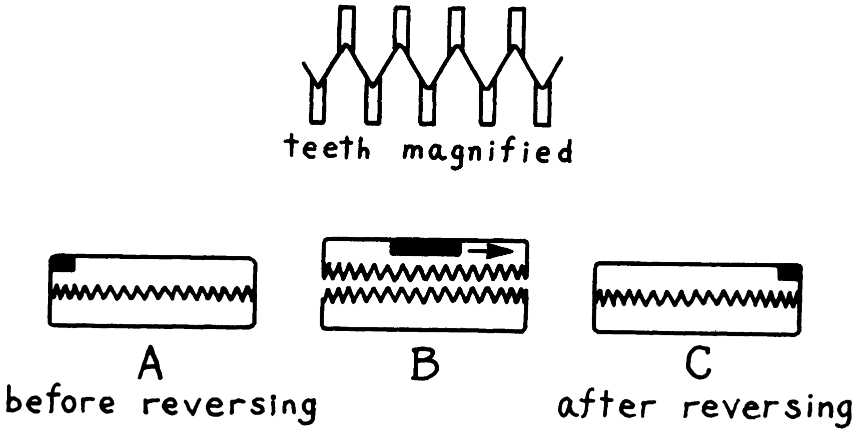

Fig. 2 The plane multiple-teeth device

2.2 The photoelectric level detecting device

Present commercial photoelectric autocollimators have an angular measuring repeatability of about 0″.02, but a larger autocollimator could achieve a repeatability of 0″.01. The two-dimensional autocollimator (with a mercury surface as an ideal level below) should be fixed to the rotary table. This would make it possible to detect any change in the tilt of the rotary table and of the fork assembly after the reversal process can be detected. The photoelectric error signals generated by these tilts changes can be transmitted to two servo systems, to trigger automatic adjustments of both the fork assembly with the horizontal rotation axis and the divided circle back to their tilt before reversal. The azimuth of the fork assembly with the horizontal rotation axis must, of course, not vary even slightly during the leveling process.

2.3 The active optics and the telescope tube

If a stable boresight with an error tolerance of only 0".02 to 0".04 is required for the Cassegrain type telescope of a transit circle, the corresponding tolerances are 0".01 and 0.1 μ for the tilt and the shift, respectively, of the primary mirror, but may be increased to 0".05 and 0.3 μ for those of the secondary mirror. Such a stable boresight is very difficult to achieve since even a well designed Cassegrain type telescope still has a boresight error of about one second of arc or larger.

Since we plan to use reflecting optics, we suggest the "active optics" technique to keep the boresight of the reflecting telescope stable. The principle of this technique is as follows:

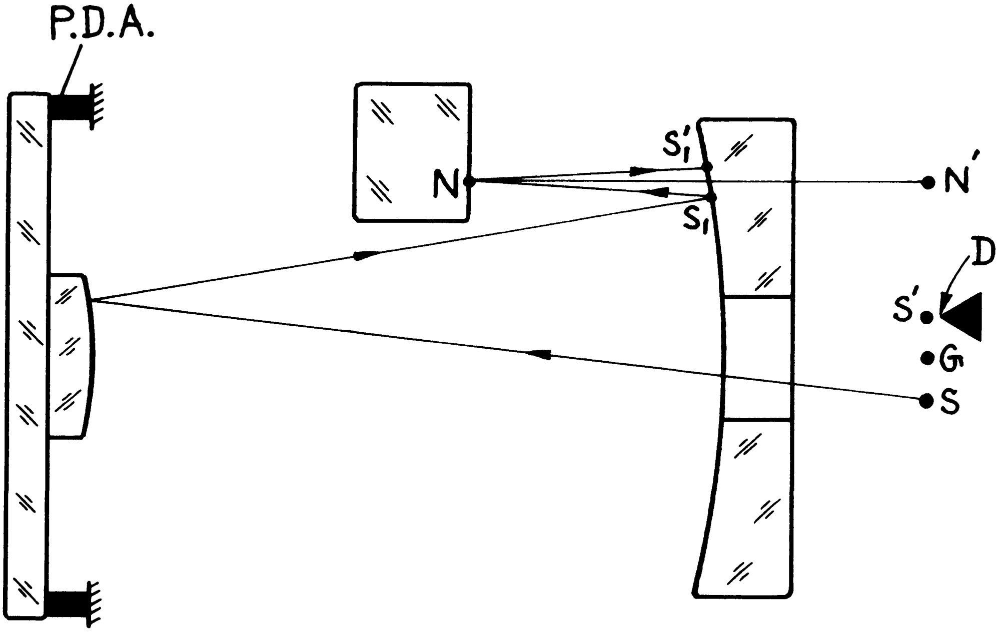

Fig.3 Principle of keeping boresight stable by active optics

A light source S and a knife-edge detector D are in the focal plane of the telescope (cf. Fig. 3). G lies at the mid-point of SD and serves as standard for observing the star image. S' is the autocollimated image of S. If a boresight error occurs, S' will not be exactly bisected by D and consequently generate a photoelectric error signal, which can be used to control the piezoelectric displacement actuator which tilts the secondary mirror until S' coincides with the bisection at D within 0".01. When the optics reach this condition and remain stable, one can prove that the boresight for G coincides with the normal N'N of the autocollimating flat. This ideal condition can always be maintaned, even for the entire range of zenith distances.

In practice, D should be a two-dimensional detector so that the boresight can be checked and corrected as needed in both altitude and azimuth.

Since both the autocollimating flat and the divided circle are rigidly attached to the same rigid horizontal axis, the normal to the autocollimating flat, which represents the boresight of the telescope, does not change its relation orientation with respect to the divided circle.

Temperature changes, which cause some defocusing, will produce with active optics a very small boresight error. Since the instrument is, however, reversed during the observation of each star within only two minutes, the total effect of the boresight error produced by a temperature change is expected to be negligibly small.

The telescope tube will be a so-called Serrurier truss, which will only cause a small shift without harmful tilt when a load is taken off the outer end of the truss. In order to obtain for a wide temperature range a focal plane which is stable with respect to the photoelectric micrometer, the truss of the telescope must be designed to have an appropriate equivalent thermal expansion coefficient equal to that of the mirror material.

The telescope tube will be equipped with a motor-driven light-weight rotary tube to reduce irregular refraction in the tube.

We hope to have a telescope tube with active optics ready for testing early in 1985.

References:

Westerhout, G. and Voliden, R. A. 1981. Bull. Amer. Astr., Sec. **13**, 445.

Mao, Wei, et al., 1983. Acta Astronomica Sinica, 24, No. 2.

Discussion:

STRAND: The collimation system designed for your transit circle is essentially the same we designed for the 60-inch astrometric reflector, which uses the secondary mirror as the autocollimator. The collimation is done photographically at the end of the regular exposures. The collimation marks appear as spots in the four corners of the photographic plates. The location of the optical axis on the plates is where the lines between the spots (one direct and on reflected) in opposite corners bisect each other if in collimation.

HU: But we add servo devices to the autocollimation system so that we can adjust the tilts of the secondary mirror in order to keep the boresight of the telescope stable.

HØG: I appreciate this new initiative in a difficult field and I appreciate the good and original ideas in the design, and I should like to offer some comments concerning the autocollimator and the large aperture. I doubt that your autocollimator can measure accurate to $0\overset{''}{.}01$ with an integration time of a few seconds because of the thermal turbulence inside the telescope.

HU: We can introduce a rotating inner tube which would reduce the air turbulence within the tube to an acceptable level.

HØG: I think that a limit of visual 12^{m} is sufficiently faint for a transit circle since there are enough stars at this magnitude within the fields of large Ritchey-Chretien reflectors by which any fainter stars can thus be observed. This magnitude can be reached by a photoelectric transit circle of 25 cm diameter. So perhaps you are taking an unnecessary risk of technical problems and instability if you choose a 40 cm aperture for your development.

HU: I think that a 40 cm instrument can give more precise results for stars as faint as 12^{m}.

TELEKI: Such a large astrometric instrument is susceptible to atmospheric factors (temperature, etc.). Therefore it is not not quite realistic to assume that — other things being equal - the zenith zero point will not be changed after the instrument's rotation. I should like to remind you of the experience with the classical vertical circle instrument: The temperature (or generally, the atmospheric) field is usually not homogeneous and for this reason the instrument, after its rotation, has to change its constants (zenith zero point, etc.).

HU: After the reversal, we use the tilt-meters to test this tilt and we adjust it for each star.