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Transit Circles Today

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SUMMARY

A brief account of how the Transit Circle has managed to survive for 250 years is followed by a survey of modern technical developments that are being applied to this venerable instrument. The various observational programmes now in progress are summarized, and the paper concludes with a few thoughts on future prospects.

INTRODUCTION

The recent rapid expansion of the physical and theoretical sides of astronomy, dating from the introduction of photography and spectroscopy in the nineteenth century, has considerably broadened the scope of the subject, with the result that practical positional astronomy has been displaced from the dominating pre-eminence which it had enjoyed for the previous three millennia.

It is often pointed out that astronomy, as a science, developed as the daughter and hand-maid of astrology; this fact may account for the early emphasis on positional work, since astrology has always been essentially an attempt to associate terrestrial events with the positions of, and angles between, various celestial bodies. Positional astronomy was developed in classical Greece for additional applications, such as sea navigation, land surveying, and some elementary geodesy. The various attempts to set up an adequate calendar system may also be regarded as applications of positional astronomy, as indeed may the many ingenious sun-dials and other time-determination instruments that have been devised since the beginning of historical records.

The modern history of astronomy is generally taken to start with Kepler, Galileo and Newton, when astronomical observations (still principally positional observations) began to yield information about the nature of the Universe by the comparison of theory and observation. The early applications of the telescope to astronomy appear to have been mainly in the descriptive field, which is hardly surprising in view of the unexpected nature of some of the spectacles suddenly revealed. The applicability of the telescope to accurate positional determination was, however, by no means ignored, but in this field the introduction of the transit circle soon after 1700 amounted to a completely fresh start.

STELLAR POSITIONS AND MOTIONS FROM TRANSIT CIRCLES

The distinctive property of the transit circle is its ability to lay down a system of celestial positions covering the entire visible sky, and to relate this system fundamentally to the celestial equator as the zero of declinations and to the (vernal) equinox point (the First Point of Aries) as the zero of right ascensions. The requirements of ocean navigation, including the introduction of the method of lunar distances for determination of longitude, and the desire to apply a rigorous test to gravitational theory, gave the transit circles plenty to do for the first century or so. The accumulation of observations of the fundamental positions of the 'fixed' stars made it possible to investigate the proper motions of the fainter stars, and thus to achieve what had been foreseen by Halley (**1**) and W.Herschel (**2**) in their studies of the proper motions of certain bright stars. The feasibility of doing this was confirmed by the discovery of the first stellar parallaxes about 1838, which showed that the stars were not after all infinitely distant, and might well therefore be expected to have perceptible individual motions. In consequence, the rest of the century saw the production of hundreds of positional catalogues based on transit-circle observations, intended to be the data for the determination of stellar proper motions (**3**).

PHOTOGRAPHIC ASTROMETRY

By 1900, however, a new factor had entered, with the application of photography to the determination of positions of faint stars. This gave a precise and efficient means of mapping the sky by means of specially designed astrographic telescopes, and it was clear that relative star motions could be measured accurately by comparing plates taken only a few decades apart. The intrinsic high accuracy of this procedure threw into prominence the essential limitations; the larger the scale employed, the smaller the area of sky covered, and the greater the difficulties of bringing the measured motions into a consistent sky-wide system. In some applications, such as the rapid detection of stars with large proper motions, the limitation was unimportant, but in the more general view it was felt essential to set up a secure framework to which the photographic positions and motions could be related in all parts of the sky.

Several procedures have been proposed and adopted for this purpose. Systematic photographic astrometry can be dated from the Astrophotographic Congress held at Paris in 1887 at the suggestion of Gill (**4**), which laid down the plans for a Chart and Catalogue to cover the entire sky by overlapping plates (**5**). Later, Hough (**6**) attempted to use stars in the overlapping areas to carry the system of one plate on to the next, and this attractively direct approach is still being pursued by Eichhorn (**7**), (**8**) and others (**8**). If success is achieved, the result will be a sky-wide

position system with its arbitrary zero directional coordinates to be assigned. The corresponding sky-wide motion system will have correspondingly arbitrary zero-points of rotation about the observer. Another approach is to take some presumably very distant objects as providing a system of zero rotation. If faint stars are chosen, we now know that their orbital motion in the galaxy needs to be allowed for, so that the zero of rotation depends on the adopted model for stellar orbital motion. This objection does not apply to extra-galactic nebulae, and there are two current programmes (**9**)–(**11**) directed toward reference of stellar proper motions to these objects. Suitable nebulae are available all over the sky except in the zone of avoidance along the Milky Way (where they are hidden by material in our own Galaxy); when this zone has been securely tied, by some other method, to the general zero-rotation system, it only remains to assign the arbitrary zero directions.

USE OF TRANSIT CIRCLES IN CONJUNCTION WITH PHOTOGRAPHIC ASTROMETRY

Another type of sky-wide framework is, of course, the 'fundamental' position system set up by transit circles. By convention, the word 'fundamental' in this context implies a frame of reference based on a dynamical theory of the motions in the solar system, including the rotational motion of the Earth. If the small area photographed happens to contain some stars with a history of transit-circle observation, these can be taken as reference stars possessing known fundamental positions, and used for determination of plate constants for evaluating the positions of all stars with measurable images on the plate. Such a haphazard approach would encounter difficulties of at least three kinds:

(1) the available stars may not be well distributed over the plate area;
(2) the fundamental positions may refer to a different epoch, so that proper motions of the reference stars will need to be applied;
(3) the reference stars may be of appreciably different magnitude and colour from the generality of stars on the plate.

These disadvantages can be avoided or mitigated if a concerted effort is organized according to a well-prepared programme:

(1) the plate centres can be decided in advance, and the reference stars chosen to be well distributed on each plate area;
(2) the reference stars may be intensively observed by transit circles at the same time as the photographic observations are taken;
(3) desirable features of magnitude and colour may be imposed as criteria in the selection of the reference stars.

Examples of this type of co-operative action are the AGK2 project (**12**) observed at several European observatories around 1930, the AGK3 project (**13**) internationally observed around 1960, the current Southern

Reference Star programme (**14**) being internationally observed at the present time, 1969, and the KSZ programme now in progress in the Soviet Union and associated countries. The reference-star lists for these projects (AGK2A (**15**), AGK3R (**16**), SRS (**16**) and KSZ (**17**) respectively) provide the transit circle with its most important and efficient role in the determination of stellar motions.

It has been suggested that the asteroids and the Moon could be used to link astrographic plates to the fundamental position system, but this would provide sporadic spot-checks rather than a sky-wide frame of reference.

CONTINUING REQUIREMENTS FOR FUNDAMENTAL POSITIONS

The principal aim of the large international projects has been the determination of stellar proper motions, but there are one or two recent developments in which attention has been directed to positions rather than motions. For example, the widespread use of optical observations of artificial satellites for geophysical and geodetic investigations has given rise to a demand for accurate and consistent star positions of current epoch. The Smithsonian Astrophysical Observatory has produced a star catalogue (**18**) intended for this kind of work, but it is inevitably a compilation based on observations with mean epoch some decades past, and so relies on accuracy in the quoted proper motions to give good current places. In another field, there is a demand for accurate current fundamental positions of point radio sources, so that more precise positional calibrations of radio telescopes can be achieved (see, for example, (**19**)). The situation will clearly improve considerably with the completion of the AGK3 catalogue (for the northern sky) and, later, with the southern sky survey; nevertheless, it would appear that there is always likely to be a need for determination of at least some current positions by direct observation in the fundamental system, which implies the continued survival of the transit circle, at any rate until the establishment of a viable alternative.

RIVALS TO THE TRANSIT CIRCLE

The Photographic Zenith Tube and the Danjon 'impersonal' astrolabe (**20**) have contributed appreciably to our awareness of the errors in the fundamental position system. Would it not therefore be possible for them to take over the leading part in positional work from the classical and antiquated transit circle? We have already mentioned the distinctive property of the transit circle, its ability to relate positions over the whole visible sky to the equator and equinox. The P.Z.T. relates stars in a narrow zone of declination to the zenith, and thence to each other. It has no access to the vast majority of the stars, and no access to the

equator or the equinox, relying for these zero-points on fundamental catalogues based on transit-circle observations. The Danjon astrolabe has access to stars over a 60° zone of declination, but it observes in a single coordinate (zenith distance, a combination of R.A. and declination differing from star to star), and again has no practical access to equator or equinox. A modification of the astrolabe proposed by Thomas (**21**) may be arranged to give access to the pole, and to cover a wider zone of declination. Thus we see that neither of these instruments can yet displace the transit circle from the fundamental role.

MODERN DEVELOPMENTS IN TRANSIT CIRCLE DESIGN

This is not, of course, to say that the optical, mechanical and metrological features of the classical transit circle can never be improved. The thirty or forty active transit circles of the world display a wide variety of detailed instrumentation and modification, and there are several new ideas being developed. Chief among these is the Mirror Transit Circle, known sometimes as the Horizontal Transit Circle (see several references cited by Dick (**22**)). This has two stationary refractors mounted in a horizontal position, lying respectively north and south of a large plane mirror which turns on a horizontal east–west axis, and directs light from a star on the meridian into one of the refractors. Another arrangement, due to D.S.Perfect, deploys the horizontal refractors along an east–west line, and has a pivoted pentaprism, or the equivalent two-mirror arrangement, to deviate the light by 90° from the meridian plane into the refractors. Danjon once proposed (**23**) a refractor transit incorporating a reversing prism so that two images moving in opposite directions were seen by the observer. At some observatories it is customary to use separate specialized instruments for each coordinate, a transit for R.A., and a verticle circle, usually reversible, for declination.

Various reflector arrangements have been proposed for use in transit circles; the Automatic Transit Circle (**24**) now being developed at Washington will have a modified Cassegrain arrangement.

Some of the many choices of configuration now available in transit-circle design are indicated in Table I.

The modern philosophy is to regard the observational instrument as a source of numerical data for processing. The information should therefore ultimately be presented in machine-readable form, and there is manifest advantage in reaching this stage as early as possible in the course of the instrumental operations. Considerable progress has been made in eliminating the human labour of computation, and a start has been made in eliminating the role of the observer, so that the astronomer acts only as an instrument operator. The next step will naturally be to

eliminate the operator also, so that the instrument can work without human presence, as in the remotely-controlled Automatic Transit Circle projected at Washington. This will lead to the possibility of operating transit circles at extra-terrestrial locations, which will raise all sorts of new problems concerning the crucial need for a stable local gravity direction, and adequate rotation theory.

TABLE I

Topic	*Choices available*
Coordinates to observe?	R.A. only Dec. only R.A. and Dec.
Optics?	Refractor Reflector Mixed
Movable part of optics?	All movable Part movable
Image detection?	Visual Photographic Photo-electric
Moving reference?	Nil Single wire Double wire Photo plate Star follower
Fixed reference?	Wires Wires or graticule
Illumination?	Field Wires Wires (flashed)
R.A. observations:	
Micrometer drive?	Hand Motor
Speed setting?	Manual Automatic
R.A. bisection control?	Manual Automatic
R.A. micrometer readout?	Visual Electric contact (not for slow stars) Electronic (at known clock times)
Chronograph?	Analogue (barrel or tape) Digital (printing or punching)
Declination observations:	
Dec. micrometer readout?	Visual Analogue (paper on drum) Electronic
Circle readout?	Visual micrometers Photographic Photo-electric Electronic
Film reading?	Manual Digitized manual Digitized automatic

CURRENT TRANSIT-CIRCLE OBSERVING PROGRAMMES

The observing programmes now occupying the transit circles of the world can be divided into those aimed at proper motions, those aimed at accurate current positions, and those aimed at the maintenance and improvement of the fundamental positional system.

In the first division, aimed at proper motions, we have many instruments working on the SRS, the reference star list for the southern sky. This includes three transit-circle expeditions from the northern hemisphere which have been established in southern observing sites (Bergedorf at Perth, Pulkovo at Cerro Calan and Washington at El Leoncito). The present series will provide what may be regarded as the first-epoch work, and it will possibly be desirable to repeat the observations about 1990 as second epoch. The main effort in the Soviet Union and its neighbouring countries is directed to the KSZ project, intended eventually to provide a link to the extra-galactic nebulae. Another international effort, on a smaller scale, is the observation of a list of double

stars which are troublesome to measure on photographs. Several transit circles are working on individual lists of stars of physical interest, such as red stars, or variable stars.

The programmes aimed at accurate current positions are generally smaller. They include radio point source positions, calibration fields (such as Praesepe) for optical astrographs, and stars needed by P.Z.T. stations to replace the stars constantly being lost because of the progressive change in their declination due to precession.

The fundamental system is maintained by observations of the bright fundamental stars by day and night, in conjunction with observations of the Sun, Moon and planets of the solar system. The minor planets are particularly useful in this work, on account of their stellar appearance, which avoids certain difficulties of observing limbs of major planets. There are various suggestions for increasing or revising the list of fundamental stars: the FK Supp list represents an attempt to increase the number and thus the average sky density of the FK4 stars. There are also proposals to establish a list of fundamental faint stars, to make the link to astrographic work more secure.

RECENT DEVELOPMENTS AT VARIOUS OBSERVATORIES

The details of work in progress at the various observatories are given in the 1967 Reports on Astronomy (**25**). More recent developments have been reported as follows.

Babelsberg

The Pistor and Martins transit circle (189 mm/2650 mm) has been transferred to the Geodesy and Gravimetry department of the Central Institute of Geophysics at Potsdam, where it is undergoing a series of tests. Photographic circle reading is being installed.

Bordeaux

A photo-electric micrometer due to Y.Requième has been used to observe some faint stars of the SRS list (in R.A. only). Tests with a transit circle at an experimental site (Dorres) in the Pyrenees (altitude 1677 m) have revealed an instrumental azimuth instability, but the micrometer worked well. Progress is now being made with photo-electric observations in declination, and with a device for the automatic observation of the Sun.

Brorfelde (*Copenhagen*)

The transit circle, modernized by the installation of a photographic micrometer and photo-electric reading of the declination circle, has completed a substantial catalogue.

Cape

The Gill transit circle has been fitted with photographic circle reading and a printing chronograph. Good progress is being made with the SRS observations.

Herstmonceux

The Cooke transit circle is now engaged on a short programme of observations of the fundamental stars and planets, with the addition of some selected variable stars which lack meridian observational history. Transfer of reductions to computer is complete, and the investigations necessary to set up an independent Herstmonceux system of star places are making progress. Proper motion determinations are continuing, with gradual transfer to computer methods.

La Plata

The transit circle (from Lick) is being overhauled prior to joining the Southern Sky Astrometric Program. The 190-mm Repsold meridian circle is continuing observations of absolute declination of southern FK4 stars at the Southern Astrometric Station, La Leona. FKSZ star positions have been reduced. Some modernization is planned.

Ottawa

The mirror transit circle is still the subject of various tests and investigations. Problems include some instability in axis azimuth, poor images at times, and difficulty in achieving adequate accuracy of circle-reading.

Perth Observatory, now at Bickley, Western Australia

The Troughton and Sims reversible transit (150 mm/1780 mm) of 1897 is in need of considerable overhaul and modernization. An expedition from Hamburg–Bergedorf Observatory, with the Hamburg transit circle, now occupies the transit house, and is making good progress with SRS observations, including fundamental stars and planets.

Porto

The mirror transit circle is having a modified mirror support system installed, making use of air bags in place of oil pressure. It is hoped thereby to remove backlash and other anomalous behaviour of the mirror suspension.

San Fernando

The 7-in. transit circle (178 mm/2661 mm) by Grubb Parsons has visual microscopes for circle reading, and a motor-driven R.A. micro-

meter recording on a printing chronograph. It is engaged on relative position observations of the SRS programme.

Tashkent

The Tashkent transit circle has completed two R.A. catalogues, namely, (1) 3148 stars to 6th magnitude, in system of FK4; and (2) 2488 stars, 7·0 to 9·0 mag., of the KSZ list, in system of FKSZ.

Tokyo

The Gautier 8-in. meridian circle of 1903 is in use for fundamental observations of Moon, planets and minor planets in the system of FK4. 3560 stars of the SRS list were observed between 1963 and 1968. The R.A. micrometer is motor driven, and the declination micrometer is fitted with a synchro system for registration. Circle readings are photographic, and the films are measured by automatic photo-electric machine giving computer-readable output. A new eyepiece micrometer, including a reversing prism and digital recording of both R.A. and declination readings, is due for installation this month. The search for a new transit-circle observing site continues.

Uccle

The work of the Askania meridian circle is now organized as part of a multi-disciplinary department which includes satellite geodesy and gravimetry by horizontal pendulums mounted in deep mines. The instrument has recently been modified. Proper motions of latitude stars are being determined.

Washington

The 6-in. transit circle is being equipped with an Inductosyn circle reading system, now undergoing final calibrations. A new analogue-to-digital system with some computer capacity will be installed soon. The instrument is in use on bright-star programmes, and is also used by staff of the 7-in. T.C. Division for observations of SRS stars. Proper motions for several lists of stars have been determined. The 7-in. transit circle has been shipped to El Leoncito, Argentina, where it is participating in the SRS programme. The design study of a 10-in. automatic transit circle, with modified Cassegrain optical system, electronic circle reading, and automatic star and planet tracking, has been completed.

CONCLUSION

It is customary, at the conclusion of a survey paper, to offer some thoughts on future prospects. For transit circles, the near future seems to contain the conclusion of the important international star-position programmes, AGK3 and SRS. Second-epoch work on SRS will be due toward the end of the century, but apart from this, the transit circle

appears to be nearing the end of its useful life. The same verdict could well have been given 100 years ago, and again 50 years ago. We may therefore reasonably expect that it will continue to be true in 50 or 100 years' time, owing to the appearance of novel and unexpected tasks which fall within the scope of that venerable, classical, but far from out-dated instrument—the transit circle.

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