Tavistock Theodolite — Théodolite de Tavistock

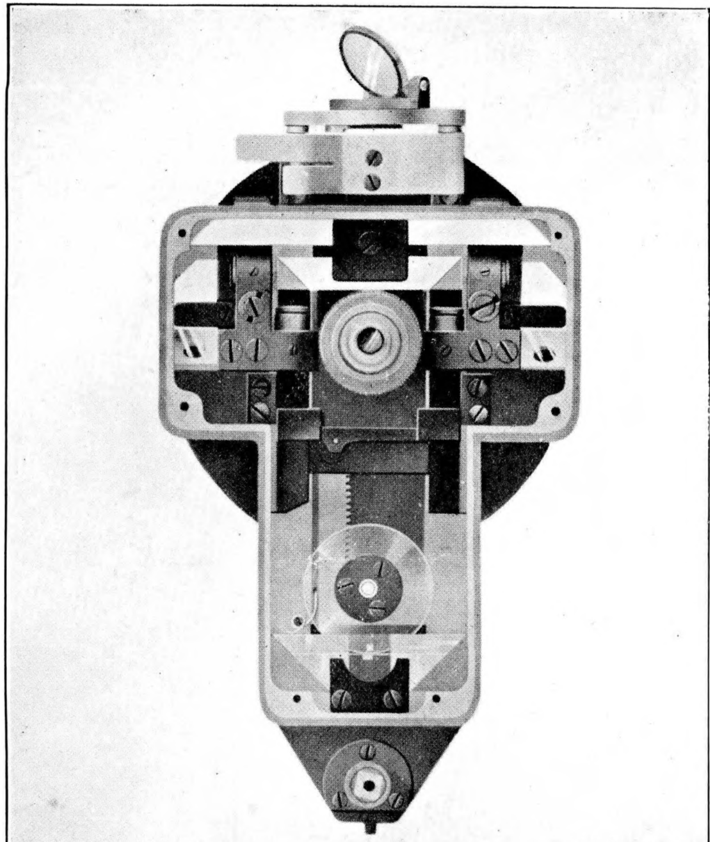

Fig. 3

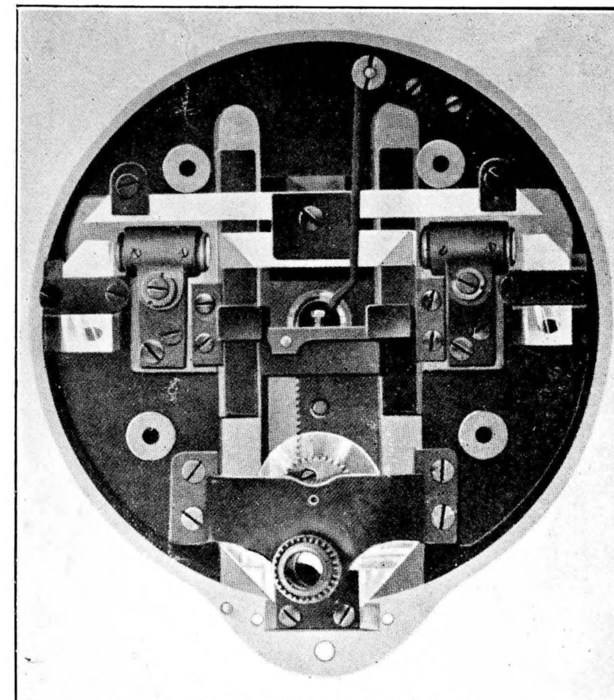

Fig. 4

THE TAVISTOCK THEODOLITE

(See *Hydrographic Review*, Vol. VII., N° 1 – May, 1930, page 206).

Since the publication of the article in the *Hydrographic Review*, several improvements have been introduced in the construction of the *Tavistock* Theodolite. The following is extracted from various descriptions of the *Tavistock* Theodolite which is constructed by Messrs. COOKE, TROUGHTON & SIMMS Ltd., Buckingham Works, York, England.

The optical arrangement and method of reading the circles of the *Tavistock* Transit Theodolite are different in every respect from other patterns. The particular feature of the method utilized is a bisection setting, thus following to some extent usual micrometer practice, in which two movable webs are brought into a symmetrical position in relation to a circle division; in the *Tavistock* Theodolite, however, two circle divisions, graduated 180° apart, are symmetrically disposed on either side of a fixed fiducial mark. Instructor-Captain BAKER's method enables readings to be taken simultaneously on two opposite sides of a circle and automatically meaned so as to eliminate centring errors.

The specification of the new model is as follows:

Circles : Horizontal - divided on glass. Figured 0° to 360° clockwise.

Vertical - divided on glass. Figured 0° to 180°, 0° to 180° anticlockwise. Zero on circle at Zenith with "circle left" and telescope horizontal.

Both circles are read by patented micrometer reading device direct to 1 sec., further details of which are given at the end of this specification.

The horizontal circle is carried on an independent axis for using the instrument for either repetition or reiteration.

Telescope : Internal focussing; 1.5 ins. clear aperture; anallatic.

Transits at both ends with the diagonal eyepiece in position.

Focussing by milled head at end of horizontal axis.

Screw-focussing inverting eyepiece, power 25, with ebonite binocular type eyecap.

Transit axis is bedded in complete round screwed-down bearings.

Open sights are fitted to both sides of telescope.

Diaphragm : Glass — simple crossed lines, with addition of stadia lines 1:100.

Fitted in a removable cell enabling the diaphragm to be readily withdrawn for cleaning purposes or exchanged with the spare one if necessary, without disturbing the collimation.

Spirit Levels : Plate : 40 secs. per 2 mm. run.

Altitude : 20 secs. per 2 mm. run.

The altitude level is provided with prism reader to enable the position of the bubble to be easily observed from the telescope eye-end when in any position.

Fine-setting screw also fitted for levelling altitude level before each sight is taken.

Tribrach : Three levelling screws with dust covers.

Weights : Instrument only : 11.17 lbs.

Box, complete with accessories, tools and spares : 10.5 lbs.

Tripod : 11.0 lbs.

Illumination : Illumination of circles during daylight is provided by adjustable reflectors. For night use, the illumination of the circles, altitude spirit level and telescope diaphragm is electrical, by standard 4.0 volt lamps which are easily accessible for replacement. Plug-and-socket fitting on tribrach for connection of wires from battery.

The rheostat and "on and off" switch are attached to the battery which is strapped to the tripod.

Box : The instrument is packed complete in a strong metal box. The box is canvas covered and fitted with web rucksack straps for carrying the instrument in a vertical position. All accessories, etc., are securely fitted in the case.

Tripod : Open-frame legs (alternative patterns in wood and duralumin, full-length and telescopic) with centring movement of 1 ½ ins. The fittings of the hinge pins which connect the legs to the head are self-adjusting. Bottom shoes are securely attached to the legs and have projections forming an effective footstep. Circular bubble fitted for rough levelling. Protecting cap for thread on top of the tripod head.

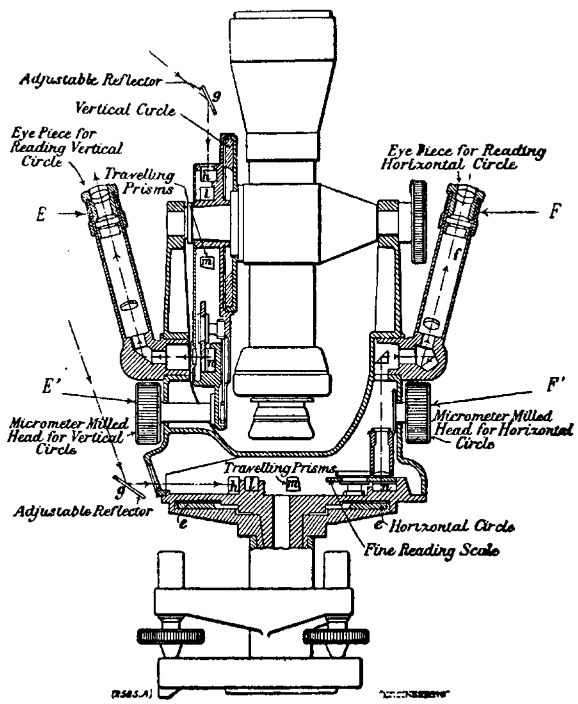

fig. 1

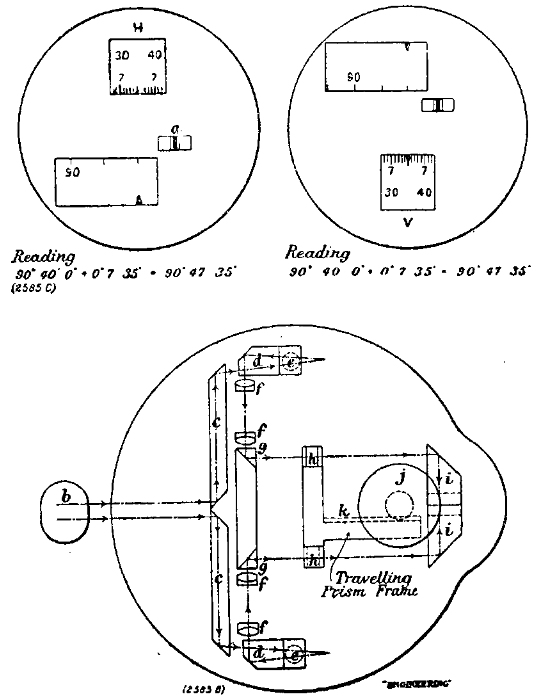

fig. 2

The section views, Figs. 1 and 2, demonstrate the optical construction of the *Tavistock* Theodolite.

Figs. 3 and 4 illustrate the vertical circle prism box and the horizontal circle prism box. (Section view, Fig. 2).

It is, of course, impossible to divide any practicable circle to single seconds, and in all theodolites the fine reading is obtained by subsidiary measurements of the angle between some fiducial mark and the nearest division of the graduated circle. The vernier has long been used for this purpose but, where specially fine readings are required, it has commonly been replaced by the filar micrometer, the cross hair of which is brought successively into coincidence with the fixed mark and the nearest division of the divided circle, the angular traverse required for this being read off a graduated head.

In the *Tavistock* instrument an optical method is used for obtaining these fine readings. In principle, but by no means in detail, it may be described as follows : The graduated circle is viewed through a microscope, but a thin prism is interpolated in the path of the ray. This causes the image of the graduation to be displaced but, on traversing the prism along the path of the ray, this image moves and can thus be brought into coincidence with a certain fiducial mark. The displacement of the prism necessary to effect this is proportional to the residual angle to be measured and, in the *Tavistock* Theodolite, this angle appears in plain figures in the field of view of the reading microscope, as illustrated in Fig. 9 of Plate A. Here the divided circle is read at the lower rectangular opening, the reading being in this case 90 deg. 40 min. The fiducial mark is indicated by the heavy black line at 3, and the fine reading is obtained by rotating the adjusting

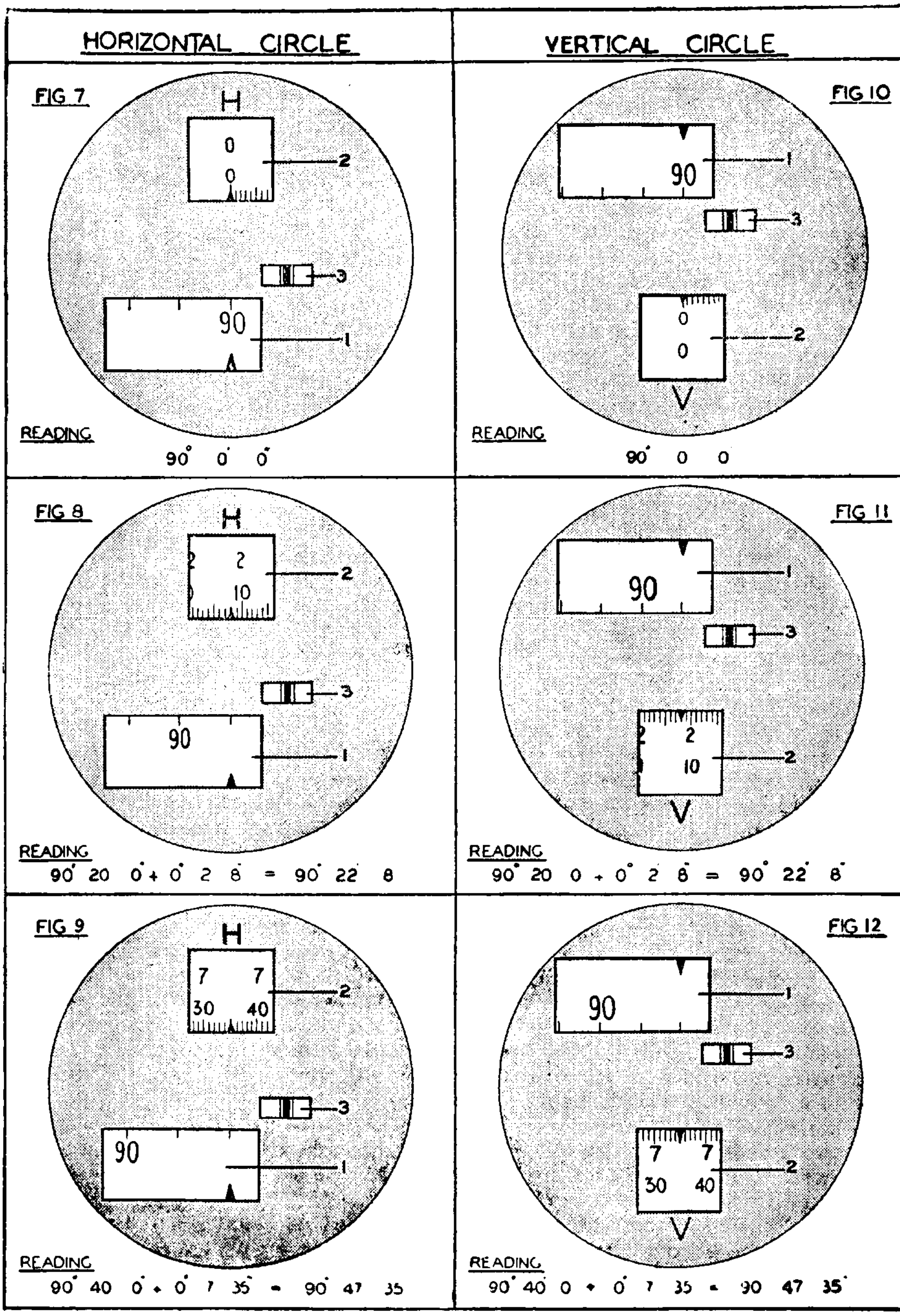
HORIZONTAL CIRCLE
VERTICAL CIRCLE
FIG 7
H
READING
90° 0' 0"
FIG 10
V
READING
90° 0 0
FIG 8
READING
90° 20 0' + 0° 2 8" = 90° 22' 8
FIG 11
READING
90° 20 0 + 0° 2 8" = 90° 22' 8"
FIG 9
READING
90° 40 0' + 0' 7 35" = 90° 47 35
FIG 12
READING
90° 40 0 + 0' 7 35 = 90 47 35"

Plate A

head until this broad black line lies accurately midway between the two side lines. This done, the correct fine reading appears in the upper rectangular opening under *H* and is, it will be seen, 7 minutes 35 seconds. This has to be added to the 90 deg. 40 min. already obtained, making the total reading 90 deg. 47 min. 35 sec. Figure 9 refers to the horizontal circle of the theodolite; a similar reading from the vertical circle is represented in Fig. 12. It will be noted that the relative position of the rectangular openings is reversed, thus materially reducing the possibility of confusion between readings of the two circles; the presence in the fields of view of *H* and *V*, respectively, being a further safeguard.

Whilst the general principle of securing fine readings is as just described, provision is made in the *Tavistock* Theodolite for eliminating automatically the error which arises from the impossibility of accurately centring the divided circles of any theodolite. Some eccentricity always exists, minute though it may be in a well-made instrument. Owing to this eccentricity, if independent and precise readings are made at opposite ends of a diameter, the two will never agree save by accident. What is required is the mean of the two readings. This is provided for in the *Tavistock* Theodolite by viewing the circle through trains of prisms arranged so that a division mark from each end of a diameter appears in the opening 3, Fig. 9. One division mark is seen on the right of the fiducial line and one on the left. In general, they will stand at different distances from the centre mark. On rotating the adjusting head, which shifts a travelling prism along each of the two rays of light received from opposite ends of a diameter of the graduated circle, these two lines move in the same direction, and when the two are equally distant from the central line the fine reading seen in the microscope corresponds to the mean of what the two readings taken at the opposite ends of a diameter would be, were these separately determined.

Coming to details, both the horizontal and vertical circles are of glass, the former being 3 ½ ins. and the latter 2 3/4 ins. in diameter. Both circles are divided to 20 minutes, so that there are 1,080 divisions in the complete circumference. The graduations are on the underside of the glass, and this is silvered. Against this silvered background, the divisions stand up as clear fine lines. The beauty of the work may be gauged from the fact that the figure 90 which appears in the lower rectangular opening of Fig. 9 is actually only 1/250 in. in height, yet appears in the reading telescope about the size shown in our illustration and absolutely sharp. The actual width of the graduations there shown is 1/5000 in., and the spacing between two is about 1/100 in. The engraving of the glass is effected by an etching process, since it was found that, though fine lines could be cut on the glass by a diamond, the cutting point thickened after cutting some two or three hundred lines. It is, of course, essential that the lines shall be the same thickness at the finish as at the beginning of the dividing operation.

A section through the theodolite is reproduced in Fig. 1. The telescope body is of drawn duralumin tubing, carefully machined to size. The object glass is of 1 ½-in. clear aperture, and the eyepiece gives a magnification of 25 diameters.

The focussing is internal, and the milled head for it is concentric with the horizontal axis of the instrument. It thus remains in the same position whatever the tilt of the telescope. The optical system is anallatic, and the glass diaphragm used is engraved with stadia lines, in addition to the ordinary cross-lines, and can be readily removed or exchanged for a "spare" without affecting the collimation. Owing to the use of internal focussing, it is easy to seal the telescope against the entry of dust and, moreover, its overall length remains unchanged whatever the adjustment of focus. It will transit either way, even with a diagonal eyepiece in place.

The horizontal axis has complete screw-down bearings and to some extent ties together the two standards, thus increasing the resistance of the instrument to accidental or careless abuse. Gunmetal is used for the main body of the instrument, thus enabling a compass to be fitted if desired.

Referring to Fig. 1, the horizontal circle is located as shown, and is read through the microscope on the right, which can be rotated round a horizontal axis into a position convenient for the observer's eye. A photograph showing the trains of prisms and adjusting gear for the horizontal circle is reproduced in Fig. 4, whilst Fig. 3 shows a corresponding view of the system for the vertical circle. The general arrangement of the prisms will, however, be best understood on reference to Fig. 2, which should be considered in conjunction with Fig. 1. Light is sent into the circle casing by the mirror *b* and, by means of the twin prisms, *cc*, is diverted right and left towards opposite sides of the horizontal circle. From the ends of the prisms *cc*, the light is reflected into the prisms *dd*, which have their reflecting surfaces at such angles that the ray which enters them travels first down to the graduated circle through the holes *ee*. It is reflected up from the silvered surface of the graduated circle, but along a path which differs slightly from that pursued by it in its first passage through the prisms. It is then directed through the objectives *ff* into the prisms *gg* and, on reflection from them, passes through the travelling prisms *hh*, and thence to the prisms *ii*, where it illuminates the graduated edge of the fine reading circle *j*. The two sets of rays which come originally, it will be remembered, from opposite sides of the main circle, are then combined and sent up into the reading microscope, through the prism train shown in Fig. 1. The optical system is arranged so that the graduations of the main horizontal circle and of the fine reading circle are both simultaneously in focus, whilst at the auxiliary opening 3, Fig. 9, can also be seen, in focus, two corresponding graduations belonging to opposite sides of the main circle, one appearing on one side of the fiducial mark, and one on the other. As already explained, these two lines will not, in general, be equidistant from the fiducial mark, and to secure equality, it is necessary to rotate the milled head shown on the right of Fig. 1 which, by means of gearing, shifts the rack *k*, Fig. 2, also visible in Figs. 4 and 3, on which the two travelling prisms are mounted.

The corresponding optical system and adjusting gear for the vertical circle differs in minor details only from that already described. The cones forming the vertical axes of the instrument are fitted without the use of abrasives, thus ensuring the permanent accuracy of these important bearings. It is, in fact, impossible to remove the last traces of any abrasive used in grinding unhardened centres, and there is thus a marked difference in the "feel" of scraped and ground centres, the former moving with notably greater smoothness.

The theodolite is provided with two spirit levels, that on the bottom plate having a bubble traverse of 2 mm. for a tilt of 40 seconds of arc. The corresponding figure for the altitude level is 20 seconds of arc. Provision is made for reading this latter level from the eye-end of the telescope by means of a combination of prisms. The tribrach has three levelling screws, with dust-proof covers, and the wear on these screws has been minimised by fitting a circular level on the head of the tripod, which can therefore be roughly adjusted before the theodolite is screwed on.

In order again to emphasise the method of reading, the following is extracted from a pamphlet by Mr. W. H. Connell :

"Each circle is read by an independent micrometer, and a circle reading eyepiece (*E* and *F* in Fig. 1) is mounted on each standard. These eyepieces are pivoted and can be swung into a convenient reading position, accessible to an observer using the Theodolite in either the "circle left" or "circle right" position. Milled heads (*E*' and *F*') for operating the circle micrometers are mounted on the standards immediately below their corresponding eyepieces. The diagrams on Plate A are typical views of the circle divisions and the fine reading scale as seen through the reading eyepieces.

It will be noted that three rectangular apertures are seen. The coarse reading (to nearest 20 minutes) is obtained from aperture 1, whilst the fine reading (minutes and seconds) appears in aperture 2 (N. B. The fine reading, which must be added to the coarse reading to obtain the complete circle reading, is always less than 20 mins.). In aperture 3, which is really two apertures separated by a broad black band, two circle divisions appear one on each side of the fiducial mark, and it will be observed in all the examples shown that these two circle divisions are so disposed about the broad black band that the narrow light gaps on either side of the reference marks are of equal width. "Setting the micrometer" consists in equalising these two narrow light gaps so that they are positioned symmetrically about the comparatively broad black band, and this operation must always be done before the circle is read.

"Setting the micrometer" is carried out by using either the milled head (*E*' or *F*' in Fig. 1) on the side of the standard, or by rotating the circle by means of its slow-motion screw. The selection of which method to use is determined by whether it is required to set the circle to some pre-determined reading, or whether some unknown angle has to be measured. For example, let it be required to measure exactly the horizontal angle between two points supposed to be 90° apart. Assume the Theodolite has been levelled, etc. Look into the horizontal circle reading eyepiece (*F*) and rotate the micrometer milled head (*F*') until the fine reading scale in aperture 2 is reading 0'0". Then clamp the circle by screw and after bringing the circle division figured 0° approximately under the arrow in aperture 1, clamp by second screw and "set the micrometer" by means of the upper slow-motion screw equalizing the light gaps on either side of the black band in aperture 3. The complete circle reading will now be 0°0'0". Next release first clamp and rotate the Theodolite until the telescope is sighted on one of the selected points. Secure circle by lower plate clamp and by manipulation of the upper clamp and the corresponding slow-motion screw, train the telescope on the second selected point. If this target be exactly 90° to the right of the first, the arrangement of the circle divisions, etc., seen in the circle reading eye-piece, will be as shown in Fig. 7; that is to say, the light gaps in aperture 3 will still be of equal width but the circle reading will now be 90°0'0".

If, however, the angle between the targets is not exactly 90°, possibly no circle divisions will appear in aperture 3, but if they do they will be disposed unequally about the black band, in which event the light gaps must be made equal (*i. e.* the micrometer must be "set" again), in this case, however, by rotating the micrometer milled head (*F'*). The rotation of this milled head also moves the fine-reading scale, and the minutes and seconds recorded in aperture 2 (after the micrometer has been set) must be added to the circle reading indicated in aperture 1 to obtain the correct angle between the two targets.

Examples of such horizontal circle readings are given in Figs. 8 and 9. In the former case the circle reading (aperture 1) is 90°20', whilst the additive fine-reading (aperture 2) is 2'8", the complete reading being therefore 90°22'8". Similarly in Fig. 0, the coarse reading 90°40' plus the fine reading 7'35" = 90°47'35".

To summarise, after "setting the micrometer" in aperture 3, read the circle divisions from the left up to and including the last full circle division (20 mins.) in aperture 1, and add thereto the minutes and seconds recorded in aperture 2.

The further examples given in Figs. 10, 11 and 12 apply to the vertical circle.

The difference in the arrangement of the three apertures in the circle-reading eye-pieces enables the user to recognise quickly which circle is being read.

The principal points of difference between the *Tavistock* Theodolite and the corresponding instruments by other makers are:

a) Readings are easier, or shall we say safer, to make with the *Tavistock* Theodolite than with instruments in which it is easy to make a mistake of 10 minutes on account of the fine-reading only recording up to half the interval between the circle divisions. With the *Tavistock* model, estimation is never necessary, and the fine-reading is simply added to the coarse reading.

b) The vertical axis is compound — there are two centres.

c) Since the whole instrument is made of non-magnetic material a compass may be attached to it. A standard T 193 type tubular compass, arranged so that the needle end is read by an eyepiece, type X 20, against a ruled glass diaphragm to within one minute of arc, is supplied.

d) The telescope transits at both ends and a diagonal eyepiece is provided.

e) The optical elements may be laid bare for cleaning or inspection with the very minimum of trouble, and such opening up of the Theodolite does not entail separation of the vital optical components.

f) The horizontal and vertical circles are read through separate eyepieces, which condition helps to prevent gross errors from that source".

A paper relating to the *Tavistock* Theodolite was read at a meeting of the Royal Geographical Society, London, on 19th January, 1931, by Major G. CHEETHAM, R. E.; a full account is given therein of the trial made with this instrument by the Ordnance Survey. The test to which the Ordnance Survey submitted the *Tavistock* instrument sent was to see if its accuracy was of the right order and what sort of speed might be expected from it. Before starting to observe, a series of tests were made with the object of seeing what sort of variation would be obtained in the setting of the micrometer for one pointing of the telescope. The instrument was then set up on a concrete block and three targets were set up at about 70 yards from it. These targets consisted of adjustable vertical slits through which the zenith light was reflected by an inclined mirror; by adjusting these slits a very fine and clear mark was obtained. A series of rounds of angles was then observed by a number of different observers. The average closure of a round of angles was (mean of 50 rounds) 2.7". The mean value of the value for the angle obtained by three observers with artificial lighting differed by less than 1 second. The average time taken by an observer to observe four rounds of angles, involving 16 pointings, two changes of face and setting on four zeros, was 20 minutes. The quickest observer took 15 minutes, less than 1 minute a pointing.