INSTRUMENTS.

NEW SMALL WILD THEODOLITE

USABLE EITHER WITH OR WITHOUT COMPASS.

Instruments for angular measurement have been greatly improved in recent years. Chief among these improvements are reduction of bulk and weight, increase in accuracy of reading, and simplification of the latter with a resulting increase in speed. These important results were confirmed at the Geometers' Congress at Zurich in 1930.

Theodolites are made nowadays which can be read directly to 1", weigh less than 5 kilos (11 lbs.) and cost less than the old-fashioned heavy theodolites of the same degree of accuracy.

FIG. 1. Scale, 2/5. *General view of theodolite.*

However, for work which does not require a high degree of accuracy, it is useful to have even smaller instruments available, with an accuracy of about 1', and with the same advantages of quick and accurate reading as modern precision theodolites.

To obtain this result it was necessary to find a new, very simple, solution for the reading arrangements; for a mere reduction of size applied to the reading devices of the large precision theodolite would result in the price being out of all proportion with the accuracy desired. The use of a less accurate instrument has nothing to commend it unless this diminution of accuracy is accompanied by an appreciable diminution in the price of the instrument.

Such a solution has been obtained by renouncing the use of a reading microscope and using a low-power magnifying glass in such a way as to read the juxtaposed images of the graduations situated on two diametrically opposite parts of the circle. In this way it is easy to read to one-twentieth of a division directly on the circle, if the size of this interval as seen in the field of view is greater than 1 mm. A device of this nature has been used since 1930 in the WILD Prismatic Compass; in the latter instrument a division represents 2° and the accuracy, for a single reading, is equal to one tenth of a division, being automatically freed from error of eccentricity (mean of two diametrically opposed readings).

The accuracy of the above-mentioned prismatic compass would not suffice for a theodolite; therefore the accuracy has been much increased by using an optical coincidence micrometer. Micrometers of this type such as hitherto used are too expensive for the present object, for they include two glass plates with parallel faces which have to turn through equal angles in opposite directions. Considerable simplification has been obtained by dividing the reading prisms into two parts and inserting between these parts a single glass plate with parallel faces; the rotation of this plate bends the rays coming from the diametrically opposite parts of the circle in the same direction, but the reflections of the rays between the plates and the magnifying glass cause the images seen in the latter to move in opposite directions, whence the possibility of making the divisions coincide.

If it is desired to be able to take readings to within one minute, the circle is graduated in double-grades, so that the grade can be read directly on the circle and the minute on the micrometer drum (which governs the rotation of the parallel-faced plate). The same arrangement is used when the scale is graduated in 360°.

Figure 2 shows the arrangement of the reading prisms and the parallel-faced plate of the optical micrometer, with reference to the circle and the reading glass.

FIG. 2. — *Lay-out of components of the optical micrometer of the new theodolite.*

(*a*) Reading prisms.
(*b*) Parallel-faced plate.
(*c*) Inverting prisms.
(*d*) Magnifying glass.

Actually, two separate magnifying glasses are used with their axes inclined in such a way as to permit of convenient reading. An inverting prism throws the images of the

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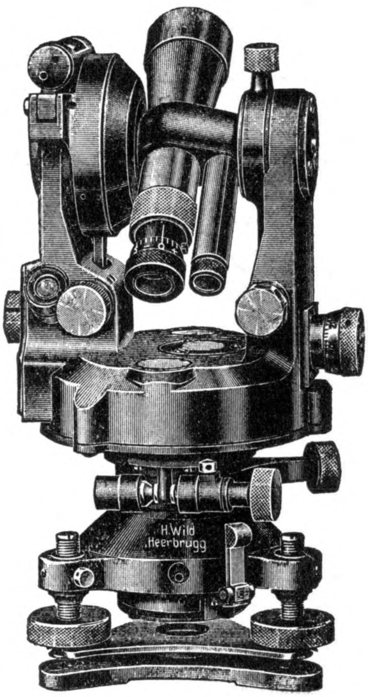

FIG. 1. *Scale - Echelle 2/5*

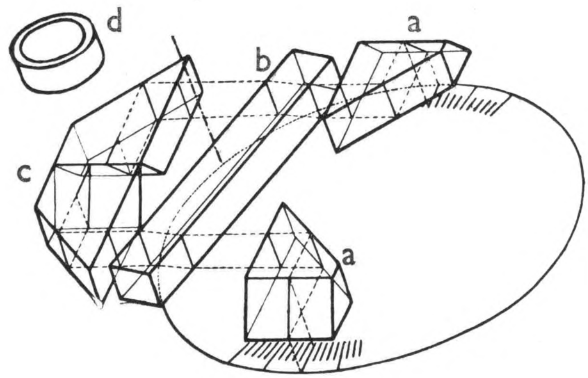

FIG. 2

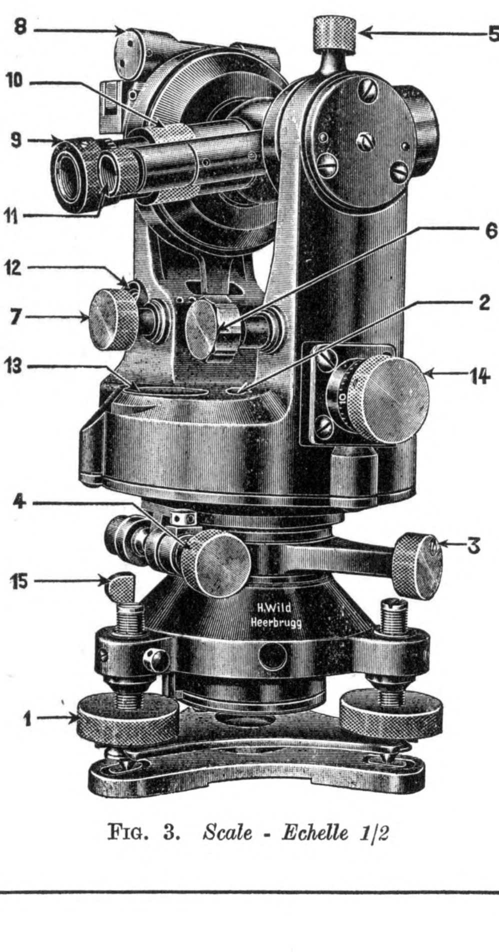

FIG. 3. *Scale - Echelle 1/2*

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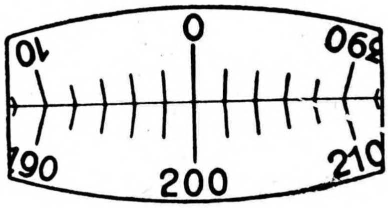

FIG. 4, *200 grades*

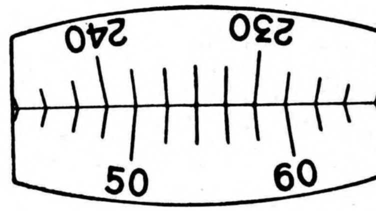

FIG. 5, *54 degrees*

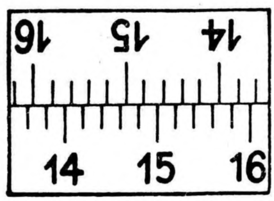

FIG. 6, *14 grades 83 minutes*

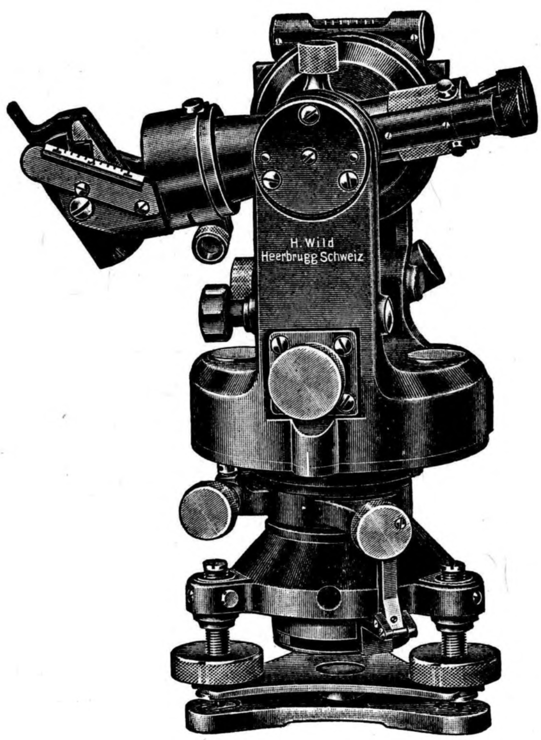

FIG. 7

Barot Micrometer *Micromètre Barot*

circle into one or the other magnifying glass, according to whether the glass is used in the 1st or the 2nd position. In this way the observer never has to turn round the instrument.

The parallel-faced plate is made to rotate by turning, by means of its milled end, a graduated drum situated on the side of the instrument opposite to the reading glasses. The screw worked by this action moves a lever, the other end of which is connected to the parallel-faced plate by a jointed link.

Considering the small magnification, this new reading device results in reducing to practically nil the effect of the accuracy of centring and small variations of the distance between the circle and the magnifying glass. For this reason it is perfectly suitable for the use of a compass card resting on a pivot and swung by a magnet solid with it.

The design of the WILD Compass-Theodolite is based on the foregoing considerations. This instrument represents an entirely new combination of the compass and the theodolite in which the same reading device and the same graduated circle are used for both the possible methods of use, namely direct measurement by the compass and ordinary measurement of the horizontal angles. In the position of rest the graduated circle is disconnected from the pivot; for this purpose it is supported all round by a collar which holds it against a counterpart forming part of the fixed base of the instrument, the latter then acting like an ordinary theodolite.

If it is desired to use the instrument as a compass, a lever is actuated which lowers the above-mentioned collar, thus letting the compass card (i. e. the graduated circle) rest on its pivot where it takes up its correct position by itself.

In the WILD Compass-Theodolite, the vertical circle is read with a microscope the eyepiece of which is alongside that of the telescope. In this microscope are seen, separated by a fine line, the images of two diametrically opposed parts of the circle. Each division represents 20 minutes (360° or 400 grades) which enables one to obtain the minutes directly by estimation of tenths of the division. To take a reading one starts from that one of the upright graduations nearest the centre of the field as one works from the lower towards the higher figures, and counts the number of divisions lying between this graduation and that with the same figure seen on the opposite scale (with the figures upside down), estimating the interval to the nearest tenth. Observing that the space thus measured between two lines a semi-circle apart is equal to double the distance between the zero mark and the fictitious index with reference to which the measurement is taken, (which is situated exactly half-way between the two divisions in question), one gives each interval half its true value, i. e. 10 minutes; thus it will be seen that the reading corresponding to the example in Figure 6 is 14.83 grades. This method of reading is used with the WILD Universal Theodolite when it is not desired to use the coincidence micrometer.

Naturally the level of the vertical circle must be adjusted before each reading.

The lay-out of the different components for working this little instrument, as will be seen from Figs. 1 and 3, is particularly noteworthy.

The instrument being designed for sights at short distances, and the angular accuracy being equal to one minute, no very great accuracy of alignment is demanded of the glass. A magnification of × 10, obtained with an excellent eye-piece, gives entire satisfaction. If, for measuring distances with such an eye-piece, stadia lines had been chosen corresponding to a constant of 100, the accuracy of the measurements would have been insufficient; but the low degree of magnification does not limit one to 100 as constant, for it is possible to double the distance of the stadia lines without the latter falling in a zone where the image is imperfect; we have thus been led to using 50 as constant. With a stave divided in double-centimetres, it is thus possible to take measurements up to 200 metres and, at that distance, it is still possible to read centimetres of distance easily.

FIG. 3. Scale, 1/2.

1. Levelling screws.
2. Spherical level.
3. Set-screw for movement in azimuth.
4. Azimuthal tangent screw.
5. Set-screw for vertical circle.
6. Actuating screw of vertical circle.
7. Screw of level of vertical circle.
8. Level of vertical circle.
9. Telescope eyepiece.
10. Telescope focussing ring.
11. Reading microscope of vertical circle.
12. Reading magnifying glass for compass dial.
13. Lighting window.
14. Knob of coincidence micrometer.
15. Lever of compass-dial clutch.

The theory of errors shows that in compass traverses the sides of the polygon must be made relatively short and not exceed 100 metres in any case; under these conditions, a stave graduated in centimetres with staggered divisions gives extremely accurate results. To make sure of the degree of accuracy which could be obtained, the observations shown in the table below were taken on a trial traverse. The measurements were taken with an instrument taken from a batch at random. No measurement was taken other than those shown. The results were entered directly into the notebook without suppression or correction.

The instrument was first placed on point 1 and the stave in succession on points 2, 3 ... 7. Afterwards the instrument was placed on point 7 and the stave on points 6, 5, ... 1. At each position of the stave, two consecutive readings were taken. The line of sight was roughly horizontal. The stave, fitted with a spherical level, was kept vertical by two struts. After the observations, the distances were measured both ways with a steel tape.

Point.	*True distance.* m.	*Reading.* 1	2	*Mean.*	*Measured distance.* m.	*Error* ε cm.	$\varepsilon\varepsilon$
1	0	—	—	—	—	—	
2	16.30	32.45	32.55	32.50	16.25	− 5	25
3	33.22	66.35	66.35	66.35	33.18	− 4	16
4	47.04	94.00	94.05	94.02	47.01	− 3	9
5	60.04	120.2	120.1	120.15	60.08	+ 4	16
6	74.56	149.0	149.1	149.05	74.52	− 4	16
7	90.58	181.4	181.2	181.30	90.65	+ 7	49
7	0	—	—	—	—	—	
6	16.02	32.00	31.95	31.98	15.99	− 3	9
5	30.54	61.00	61.00	61.00	30.50	− 4	16
4	43.54	87.0	87.1	87.05	43.52	− 2	4
3	57.36	114.8	114.8	114.80	57.40	+ 4	16
2	74.28	148.6	148.5	148.55	74.28	0	0
1	90.58	181.2	181.2	181.20	90.60	+ 2	4

$[\varepsilon\varepsilon] = 180$

Mean error of a single measurement $= \sqrt{\frac{180}{12}} = \pm\ 3.9$ cm.

The mean error of a measurement (comprising two readings) for any distance between 16 and 90 metres is $\pm$ 4 cm.; this degree of accuracy, which may be considered amply sufficient, could not be obtained with a telescope of $\times$ 20 to $\times$ 30 magnification fitted with stadia lines corresponding to a constant of 100 and using a stave divided in centimetres.

To satisfy certain exigencies, the instrument is also made with a telescope of $\times$ 16 magnification and stadia divided into hundredths. In this case, the distance measurements are taken with a new model of micrometer (Barot system*) enabling the inaccuracy due to estimation in the direct reading of the fractions of the divisions on the stave to be eliminated.

Fig. 4. *Reading of horizontal circle, 200 grades*
(minutes read on the drum).

Fig. 5. *Reading of horizontal circle, 54 degrees*
(minutes read on the drum).

Fig. 6. *Reading of vertical circle, 14 grades 83 minutes.*

(*) *French collaborator with the firm of Wild.*

It is well known that tachymeters with vertical staves are not fitted with reading micrometers on account of the variation in the value of the apparent intervals of the stave with the inclination of the glass. If p is a true interval on the stave (1 cm. when using a stadia pole divided in hundredths), the apparent value of this interval becomes equal to $p \cos \alpha$ when the glass is inclined at an angle α from the horizontal. Under these conditions, for a reading micrometer to be valid, it is necessary, when working from one end of the scale to the other, to cause the rays passing through it to be displaced by an amount the projection of which on the vertical plane passing through the axis of the glass will be equal to $p \cos \alpha$, so as to cause a vertical displacement of the image equal to a division of the stave whatever may be the inclination of the glass.

The new micrometer, of the type with a parallel-faced plate, satisfies this condition; when the plate is made to pass from one extreme position to the other, by turning it round an axis which lies in a plane parallel to its working faces, the rays passing through it are shifted, parallel to themselves, by 1 cm. in a plane perpendicular to this axis. This axis, which is also always contained in a plane perpendicular to the axis of sight of the telescope, is horizontal when the latter is horizontal; and is linked to the movement of the telescope round its trunnions, in such a way as constantly to make an angle equal to the angle of inclination of the telescope with the plane passing through

FIG. 7. *Theodolite with Barol micrometer for measuring distances.*

the axis of the trunnions and the axis of sight of the telescope. Under these conditions, the projection, on the vertical plane passing through the optical axis of the telescope, of the maximum deviation p given by the micrometer is definitely equal to $p \cos \alpha$, which corresponds to a displacement of the image of the stave equal to one division. The micrometer is mounted on a bracket concentric with the barrel of the object glass and free to turn about this barrel; the mounting is fitted with a pinion concentric with itself, in mesh with a fixed pinion of the same diameter, centred on the axis of the trunnions. In this way the axis of the micrometer, horizontal when the telescope is horizontal, turns through the same angle as that through which the telescope turns. The micrometer scale, inclined at 45° from the axis of the glass to allow of easy reading by merely raising the head slightly when leaving the ocular observation, allows of reading to a fiftieth of a division, or 2 cm. of distance, the stave being divided in centimetres.

With this micrometer, distances are read as follows:- A stave graduated in centimetres is used, placed vertically at the point to be measured. The index of the micrometer is placed on the zero of the scale and the stave is sighted on. By means of the actuating screw of the vertical movement, the upper stadia line is placed on an even division of the stave, e. g. on 1 metre. Then by tilting the plate about its own axis an even division of the stave is brought on the lower stadia line. The reading of this division, less that previously taken on the upper line, gives the number of metres of the inclined distance; the micrometer scale then shows the decimetres directly, and by estimation the centimetres. The reduced distance to the horizontal is obtained by multiplying the distance thus obtained by the square of the cosine of the angle of inclination of the telescope. In many cases it is advantageous to take not the separation of two divisions but the middle of a division as sighting points for the stadia lines.

With a glass of × 16 magnification, stadia graduated in hundredths, and BAROT micrometer, the mean error for one measurement, up to 110 metres, is ± 4 cm.

Observing that the compass-theodolite must be capable of use at all points on the earth, it must be possible to allow for the variable influence of terrestrial magnetism on the equilibrium of the compass-dial. For this reason, the dial carries little movable masses; to make such an adjustment three screws in the lower part of the compass-dial casing are unscrewed, and the upper part of the instrument removed, which gives access immediately to the little adjusting masses. The pivot point for the compass-dial may be withdrawn and replaced, the part that carries it being detachable from the instrument by way of its lower part; the point can thus be rapidly changed if it happens to be damaged by a false manœuvre.

The weight of this remarkable little instrument is only 2.2 kg. (4.8 lbs.); its maximum height is 21 cm. (8.3 in.) and its maximum diameter does not exceed 11 cm. (4.3 in.).

The metal case is air- and water-tight. The weight of the instrument in its case is 3.4 kg. (7.5 lbs.).