NEW THEODOLITE FOR PRIMARY TRIANGULATION

(Extract from an article by D. L. PARKHURST, published in *The Military Engineer,* Vol. XXIV, N° 133 - Jan-Feb. 1932, Washington, D. C.).

A new 9-inch theodolite has been designed and constructed in the shops of the United States Coast and Geodetic Survey. Its ease and rapidity of operation, its light weight, and the high degree of accuracy secured with it, have resulted in this theodolite being adopted as a standard instrument for first order triangulation, after having stood a severe field test of several years' duration.

The first theodolite used by the Bureau was one purchased in Germany by Ferdinand R. HASSLER, founder of the Survey. This cumbersome instrument had a horizontal circle 24 inches in diameter and was very heavy. During the period of its existence of over one hundred years, the Engineers of the Survey have seen the size and we ght of such instruments steadily decrease as progress in the mechanical arts permitted, until the latest first-order theodolite to be used has a circle only 9 inches in diameter, and weighs only 30 lbs.

To obtain first-order results, the accuracy of such instruments must be such that the average closure of triangles measured with it will be within one second. As the sides of an angle of one second diverge only 1 foot at a distance of 40 miles, the accuracy of each element of the instrument used in such high grade angle measurements may be readily appreciated. For instance, a play of 1/100,000 part of an inch in the vertical bearing may result in an error of about one second in a measured angle.

It is necessary to guard against the effects of changes in temperature, changes in the viscosity in the oil used, warping of the metals as they age, etc... As surveying of first order accuracy is carried on at night, because of atmospheric conditions, unusual illumination devices on the theodolite must be provided and extra precautions are taken to reduce friction and infiltration of dust.

In the new instrument these elements of design have been carefully worked out.

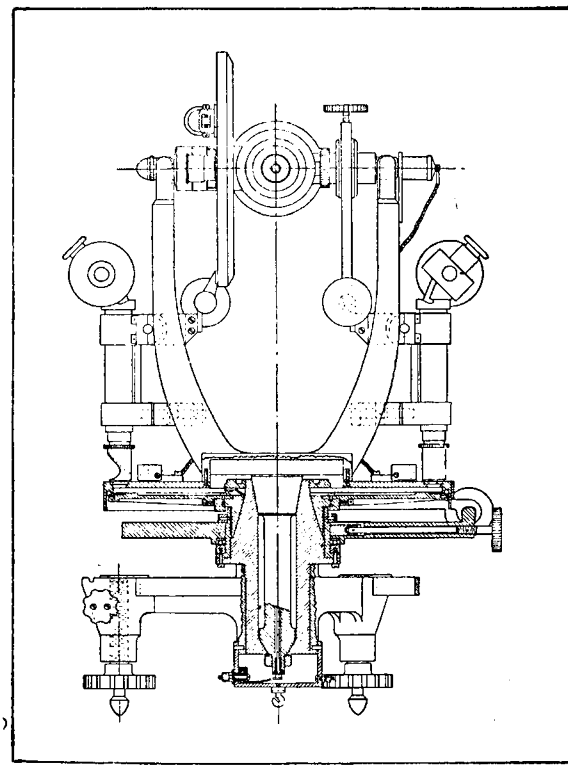
The instrument is mounted upon a three-armed levelling head of stiff aluminium alloy of U-shaped cross-section in order to give it a maximum of rigidity with a minimum of weight.

The levelling screws are of steel with threads smoothly and accurately cut and carefully fitted into split threaded holes in the levelling head. When clamped there is no play whatsoever between the screw and the head. Rigidity in the levelling head is an absolute requirement in instruments of first order precision.

A great deal of attention was paid to the design of the vertical axis because any play in it occasions an uncorrected error in the readings.

Errors due to play in the vertical axis cannot be eliminated by methods of observing. It has been the experience of the engineers of this Bureau that the frequently used single tapered bearing is not satisfactory. The alidade is of necessity quite heavy and with a long slender taper there is a deciced tendency for it to bind. In such a bearing, changes in temperature may readily cause the axis to lock or to become loose. Most manufacturers put an adjustable thrust bearing at the bottom of the axis to take up these variations, but it has been the experience of this Bureau that such a thrust bearing is none too satisfactory, especially where there are rather rapid and large changes in temperature. Furthermore, the proper adjustment of a bearing of this sort is a matter of considerable skill. Too great a lifting of the alidade will allow tilting of that element, throwing an uncompensated error into the readings, and too little lift will cause friction and possible drag in azimuth of the levelling head (and circle), which also cause an uncompensated error.

In view of the trouble encountered, use was made of the two-cone principle designed by Mr. E. G. FISCHER, formerly Chief of the Instrument Division, who used this type of bearing very successfully on his 12-inch theodolite several decades ago. This older bearing was only made immune from the effects of temperature changes by virtue of careful selection of the materials of axis and socket to insure practical coincidence of their co-efficients of expansion. In the new bearing the acute cone at the top which serves as a guide, and the obtuse cone at the bottom which takes the thrust, have coincident apexes. As a result the elements of these cones in both axis and socket are elements in similar triangles and expansion both laterally and longitudinally are proportional in each case, and when the bearing is once fitted the fit is maintained even though the effect of temperature on the one part may be different from its effect on the other. Temperature-change tests made through a range of as much as 125 degrees Fahrenheit and use in the field show that the instrument performs equally well at all practical temperatures. The angles of the axis are so designed that only a minor amount of friction remains, only the amount needed to give the proper "feel" in the turning of the alidade. The socket is made of fine grained cast iron, tightly threaded into the aluminium levelling head. The axis is made of fine grained tool steel which is left unhardened in order to insure that there shall be no residual strains which may eventually release themselves and cause a warping of the part. The axis is pierced throughout its length with a small hole to allow the introduction of an insulated wire for the electrical illumination.



The standard is of hard bronze attached firmly to the vertical axis by means of four large screws. The telescope rests in Y-shaped bearings at the top, one of which is split and has two opposed screws for adjustment, lifting of the telescope being effected by compressing the sides of the Y together. This is an extremely simple and satisfactory method of adjustment.

The slow tangent screw is somewhat unusual in its design in that the actuating part bears against a lug on the clamp arm and does not rotate. The thumb wheel is in the form of a nut which turns about the tangent plunger proper, which is restrained from rotation. The thumb nut revolves in a nicely fitted bearing and moves the plunger back and forth longitudinally. It is the usual practice to construct such a slow motion device by merely having a screw attached to the thumb wheel, passing through a threaded hold in a casting, the point of this screw pressing against a lug on the alidade. Should there be any eccentric motion of the point as the screw is turned, it may cause a lifting effort to be imparted to the alidade or cause an irregular motion, all of which may result either in error in reading or slowing down the process of pointing the telescope. It is quite essential for fast observation that the telescope move smoothly and rapidly as the tangent screw is turned and there should be little or no lag to the motion regardless of which way the screw is rotated.

Test of the initial model of this new theodolite showed that about half of the friction of rotation of the alidade occurred in the clamp and this part was accordingly redesigned to incorporate a large thrust ball bearing, and this feature has undoubtedly contributed largely to the unusual speed which has been obtained with this theodolite. The clamp is of the radial type, having a rectangular block which is pushed up against a braking surface by means of a thumb screw. When the clamp is released, however, pressure is not merely withdrawn from the block but the block is actually pulled away from the braking surface, allowing the alidade to swing entirely free. The radial type of clamp is superior to the tangential because there is no force introduced in azimuth by the act of clamping. The clamp is made in two halves and may be removed for cleaning by loosening two large screws. These screws cannot be removed and therefore lost. They are simply backed off a number of turns, releasing the two halves of the clamp, which may then be pulled apart.

The horizontal circle is approximately 9 ½ inches in diameter, with a ring of graduations 9 inches in diameter. The circle is made of bronze, carefully heat-treated, and has a silver ring soldered to its upper surface, upon which the graduations are ruled. The circle may be rotated upon a bearing formed upon the outside of the cast-iron vertical socket, the bearing being of the single cone type as some friction is desired at this point. The circle may be described as full-floating as there is absolutely no connection between it and the alidade, consequently rotation of the alidade cannot cause any frictional drag upon the circle. It is the Survey's practice to adjust the circle so that its eccentricity shall not exceed a maximum of 10 seconds. When once adjusted, the circle is locked firmly to its bearing, even if the instrument is inverted, by means of several large machine screws.

The micrometer microscopes used on this theodolite are of a new design. In order to economise in their cost the design was adapted to make use of commercially available eyepieces and standard microscope objectives. As these objectives are designed for biological work, they are of excellent definition and usually clear readings of the circle can be made with them. In it the runner is mounted on four steel balls running in carefully made V-shaped races and, as a consequence, the runner moves with practically no friction and readings may be made either with or against the spring.

In order to allow the observer to assume a convenient position when reading, the micrometer is tilted at 45 degrees, a Stellite mirror being used between the micrometer and objective in order to bend the light rays. This design permits the use of a standard eyepiece in a vertically mounted microscope whereas otherwise it would be necessary to use an eyepiece having a prism incorporated in it, which is an intricate and expensive form of construction.

A novel feature of the theodolite is the use of a carefully ground ring of milk-coloured glass for the micrometer drum, graduated and numbered by etching. A small flashlight bulb introduced inside the ring furnishes a soft light which does not have a dazzling effect upon the observer's eye, and permits quick and accurate reading of the micrometer. A similar bulb provides illumination of the horizontal circle, lighting of the several bulbs being accomplished by the pressing of keys.

The Survey has recently developed a new material for cross-wires for the telescope and micrometer microscopes. Three methods of producing the cross-wire effect are in general practice: in one a ruled diaphragm of glass is placed at the focal point of the telescope; in another, properly spaced threads of spider web are fastened to a ring of metal which is mounted at the focal point; in the third method fine threads of metal, such as platinum or tungsten, are used in place of spider threads. Each of these methods has advantages and disadvantages peculiar to itself. The diaphragm, upon which very fine lines can be ruled, has the objectionable characteristic of collecting dirt which cannot be easily removed, at least not without disturbing the adjustment of the instrument. Threads of spider web are rather difficult to mount because of their fragility and are subject to stretching under humid atmospheric conditions. When they become slackened, they sag and curl and are consequently useless. The metal wires are, of course, opaque and appear as very black lines in the field of view. They are, however, rather difficult to mount and are easily bent if touched. Both the spider thread and the metal wire systems have the advantage of passing all of the light to the observer's eye, except that which falls directly upon the wires. There is no lessening of the illumination as by a diaphragm of glass.

The Survey has developed a process for producing very fine wires of glass and these appear to have all the desirable characteristics of the various other materials and none of their defects. The open reticule may be used so that all of the light coming through the objective lens passes to the observer's eye. The glass wires are entirely unaffected by moisture and by changes in temperature. They appear as dense black lines in the field of view, are strong and stiff and are not bent when touched. In fact it is possible with ordinary care to clean away any flocks of dust which may have adhered to these threads without in any way disturbing the adjustment of the instrument. Wires as fine as spider-thread are drawn using ordinary stirring-rod glass.

The telescope used on this instrument is about 18 inches in length, has an objective of 2 ½ inches clear aperture and a 40-power eyepiece. The resolving power is from two to three seconds.

The telescope is provided with a vertical circle 6 inches in diameter which may be read to 10 seconds by means of verniers.

Because of the trouble experienced with dust in desert country, an unusual dust baffle was designed for this vertical circle. It was desired to avoid rubbing contacts as a dust guard, so a system of narrow clearances and interlocking tongues and grooves was designed, which has proven very effective, the instrument being tested by placing it in a chamber so that a blast of dust-filled air was directed against it from various angles. Fine furnace flue dust was used, and no particles got past the baffles to the graduated surface during an hour of test. The design is such that the guard may be removed by taking off only one nut, which in no way disturbs any adjustment.

In so high powered a telescope, the field of view is necessarily rather restricted and pointing on a faint light is accordingly difficult, especially for an inexperienced observer. A convenient pointing device has therefore been provided.

The pointing device consists of a half lens mounted on the telescope near the eyepiece and focussed upon a small piece of ground glass near the cross axis, blackened except for a small inverted letter V, which is illuminated by a small flashlight bulb. The lens and V are aligned with the optical axis of the telescope and the observer may readily sight through the half lens, bringing the V and the signal light into coincidence, upon which the light appears approximately in the centre of the field of view of the telescope.

The first of the new model theodolites has been used in the field for several years and remarkably accurate and speedy results have been obtained with it. It was used continuously for nearly two years without other attention than what could be given it in the field, and, when finally returned to the Office for inspection, it was only necessary to clean the instrument and replace a worn tangent screw.

A record for the Coast and Geodetic Survey for speedy observing was made with this instrument at a station where five angles were measured in 45 minutes. Each angle was measured in the usual manner for first order work, namely, using sixteen different positions of the circle, with two pointings for each position, making a total of one hundred and sixty separate pointings completed in 45 minutes.

The instrument is no heavier than commercial instruments of the same general type, but it is planned to reduce its weight by several pounds in the near future. The care which was taken in designing to insure that the new theodolite would be free from temperature effects, reasonably light in weight, convenient to operate, and easy to clean and adjust has been fully justified in its results in the field, and the Survey plans to make use of smaller instruments of similar design for second order work.