THE GURLEY TELESCOPIC SOLAR TRANSIT

IT'S USE AND ADJUSTMENTS

Bulletin No. 112-T

W. & L. E. GURLEY TROY, NEW YORK, U. S. A.

FOREWORD

This bulletin has been prepared to answer many questions in reference to the Gurley Telescopic Solar Transit. It is descriptive of the construction, operation, and usefulness of this instrument in land surveying practice.

The theory of instrumental orientation by use of the solar attachment is explained briefly, supported by a statement of the adjustments and tests in specific reference to the construction of the Gurley unit.

In-as-much as the text books on surveying have not, up to this time, given the deserved attention to this type of solar unit, the many explanations have been written explicitly, so that, in this form the text is adapted to student instruction, believing, as we do, that every civil engineer who may engage in land surveying should appreciate the speed and accuracy of this instrument.

The solar unit is mounted upon a superb engineer's transit perfectly equipped for the observations and general practice incident to land surveying.

The speed and accuracy of instrumental orientation for which the solar transit is designed, and is capable of performance, has much usefulness in many types of land surveys, including preliminary surveys of all kinds. Exploration and reconnaissance surveys; ground control for air photos; rights-of-way; farm, timber, and oil-field surveys; landscaping, where a minimum of cutting to remove obstructions is most necessary.

Wherever the engineer desires to record the direction of a line in terms of angular measure counting from the true meridian, and including also the general uses of the one-minute transit, the instrument will be a profitable investment. Its usefulness is so broad, and the solar transit so rapid in operation, the saving in field-party time pays the initial cost.

The reader is presumed to have a copy of the current Gurley Ephemeris, wherein the related subjects in reference to observations on the sun, and Polaris, and the necessary data are supplied.

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Surveying with the Solar Transit

A large proportion of the work in land surveying calls for reasonable accuracy, at reasonable cost, with directions of lines referred to the true north at the place of the survey. These are jobs that may take only a few hours time, seldom over a few days, the larger areas being an exception. What is wanted is to get started without delay, yet reasonably accurate. An instrument is needed that can perform well without having to depend upon references in azimuth, and without having to run a back-sight line if there are trees, tall undergrowth, or other obstructions. This also calls for passing short turns and offsets, where long back-sights may be impracticable, or consume much time of the field party, if the accuracy is to be maintained. These are the time and cost saving features of the solar transit, without undue sacrifice of accuracy.

In the general daily practice, the orientation to the solar meridian may be secured in a few minutes time, doing so without reference to any previously ascertained azimuth line, keeping within a normal tolerance of 1′ 30″, and usually closer much of the time. Where still better accuracy is desired, the direction of the line may be verified by the direct altitude observation on the sun for azimuth. The latter can be followed in the late afternoon, if desired, by a Polaris and other stellar observations, usually completing the observing program before illumination is required.

Usefulness of the Solar Transit

The question is frequently asked, what are the special advantages of the solar transit for use in general land-surveying practice? Its uses might be summarized briefly, as follows:

On the survey of the right-of-way for railroads, highways, power lines, pipe lines, canals and ditches, which constantly intersect property boundaries, where the directions of lines in terms of angular measure from the true meridian are always needed, and where the saving in time, and the cutting out of lines, are important factors in the cost of the survey.

The running of short control lines for fixing the relation of air photos, both for scale and orientation; no other instrument can do the job so quickly.

For the traversing of the banks of streams and lakes where covered with timber or undergrowth.

Where mapping and spotting contours by transit methods, even if there are no obstructions. Such surveys may proceed at half the expense of ordinary transit methods, and usually with much greater accuracy unless an unwarranted amount of time is expended in opening the lines and setting marks for back-sight.

Other uses, first of all, for setting a reference mark in azimuth when preparing for the daylight stellar observation.

Secondly, as a constant check of the magnetic declination, and ample warning of magnetic storm, where the needle is to be relied upon for surveys of a lower order of accuracy.

Third, for quickly checking the azimuth of any line, when making the search for an undetermined discrepancy.

When planning for new developments that are to be undertaken, the solar transit is an ideal instrument for all types of preliminary surveys, reconnaissance, and explorations, probably the most useful article in the equipment of the engineer.

Simplicity of Operation

Another question that is often asked, — What special background is required, or special training on the part of the engineer, for the proper operation of the solar transit? The background is found in the elements of applied field astronomy. It is extremely helpful when first becoming acquainted with the solar transit to go through the manipulation with someone who is familiar with the instrument, as the questions may be more easily answered by demonstration. The practical phases of the subjects are few however, and may be explained in simple terms.

The theory and practice of making the altitude observations upon the sun for azimuth is probably of first importance, because that involves an understanding of the computations for the sun's declination, and requires the value of the latitude of the station. The latter two elements supply the important data for the operation of the solar unit. The azimuth observation by the altitude method gives a convenient check to verify the instrumental orientation.

The latitude observation upon the sun at meridian passage for time and latitude is extremely useful. Also, the observation on Polaris at sunset for azimuth and latitude, hour angle method. The solar unit greatly simplifies the making of these observations, because a reference mark in azimuth may be secured so quickly. The combinations of these methods makes for the greatest possible usefulness of the solar transit.

On exploration surveys, where there may be considerable uncertainty in both latitude and longitude, these observations, together with radio time signals, will enable a quick and reliable determination of the position. Where the latitude value is quite uncertain, the noon solar observation may be reversed as to the usual procedure, i.e. — having made an approximate solar orientation in the a.m., make the noon observation by setting off the calculated noon declination (corrected for refraction) then bring in the sun in the solar telescope by the latitude tangent motion. This gives an "instrumental latitude" for the solar unit, which may be employed at once in the steps leading to the determination of the more exact values in latitude and azimuth.

On the larger or more extensive surveys where the chief engineer takes full responsibility for the supervision of the transit party, the assistant engineer will be required, as a minimum, to make the calculations of the sun's declination in preparation for each day's work, and to compute the difference in latitude from station to station on the job. With that accomplished, the work of the field party is greatly simplified as compared with ordinary transit methods, as when oriented by the solar unit all angular values count from the meridian. Much of the problem of accuracy in transit methods does not enter into the work to be done at the solar station.

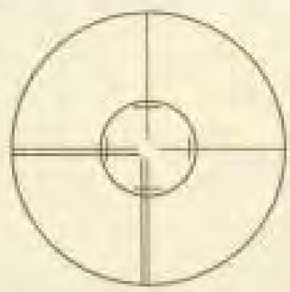
Description of the Gurley Telescopic Solar Transit

The instrument selected for association with the solar unit is the Gurley No. 112 Standard Precise Transit, Reconnaissance Model. This is the smallest of the three Gurley one-minute transits, excluding the Explorer's Model. A larger instrument is unnecessary for the performance for which the solar transit is designed. Taken together, it is well proportioned in all of the many details of design with careful regard to the compactness and minimum weight which are of essential importance in much of the work where the solar transit is best suited to the survey requirements, consistent with the specified accuracy of instrumental performance.

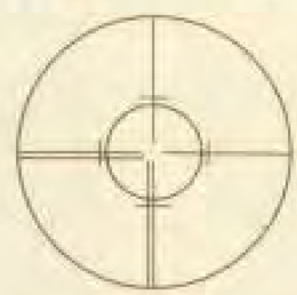
The transit is capable of securing triangulation closures within 0'20" on lengths of sides up to 15,000 ft., when using the method of repetitions; and, to give latitudinal and meridio .al results within an accuracy of 0'20" by stellar methods of observation, or by altitude observation of the sun.

The diameter of the horizontal limb is 5⅛ inches; the vertical limb, 5 inches. The compass needle is 3½ inches in length, with adjustable variation circle. The telescope level is 5 inches long. The weight of the transit with the solar unit added is 11¾ lbs.

The reticle of the transit telescope provides a "solar circle" spaced on a radius of 15'45" for the sun's semi-diameter, July 1 period; stadia lines, for both vertical and horizontal rod; double cross-lines at left and bottom (direct position of the telescope) spaced at 40" apart. The eye-piece cap has a darkener glass.



Stadia ratio: 1:132



Stadia ratio: 1:100

The solar circle is to secure exact coincidence in horizontal and vertical angle readings when making an altitude observation on the sun for azimuth; this aids materially in making the altitude observation, and reduces the observing time in accomplishing coincidence; all readings count to the sun's center.

The horizontal rod is helpful when taking stadia readings on steep vertical angles.

The double cross-lines give additional refinement in all pointings or sightings, where needed or desired, and greatly aid the visibility in the daylight stellar observations.

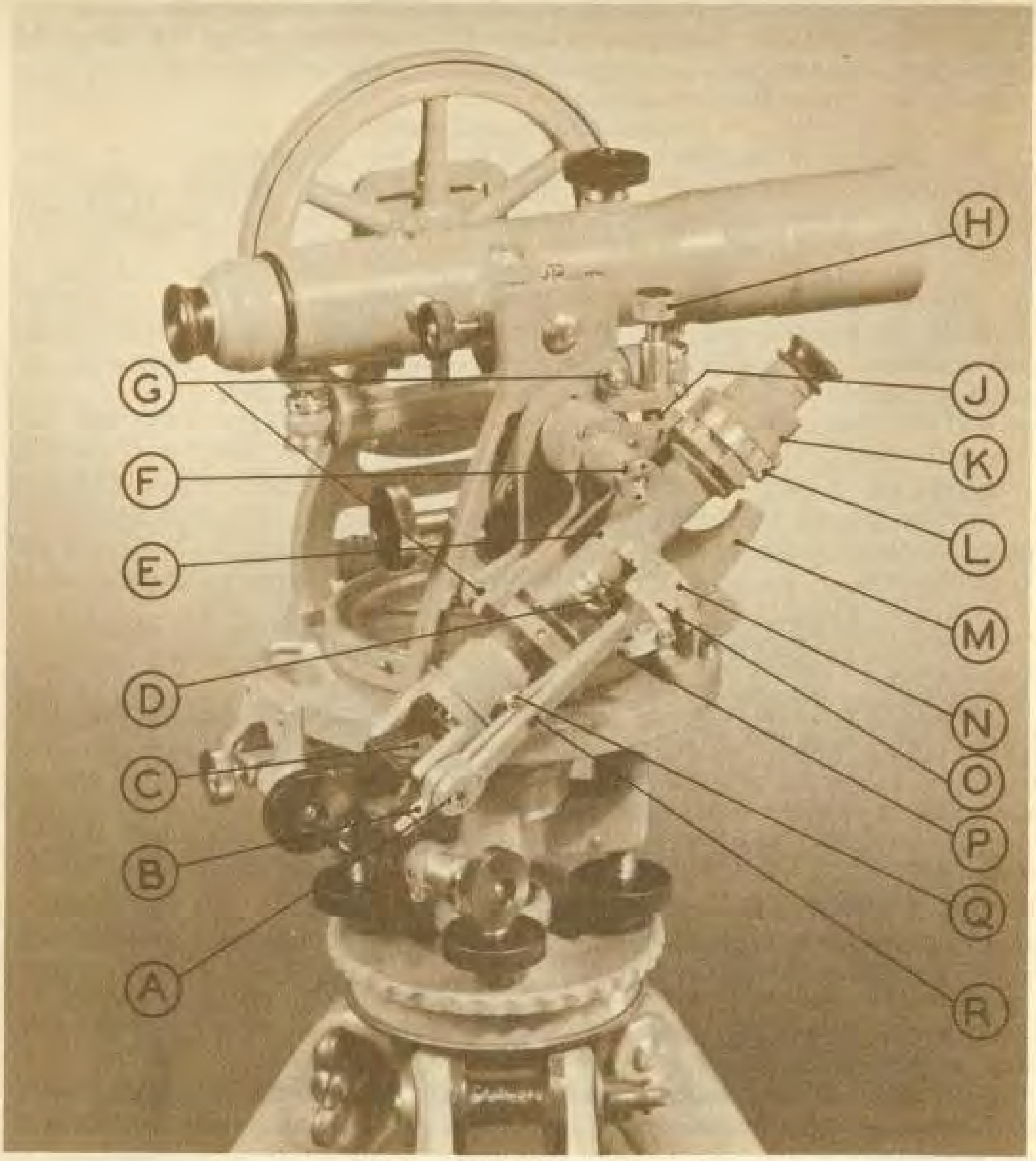
Design and Construction

The solar unit is mounted on the east standard, opposite to the vertical circle. It is secured by three threaded studs, placed to form a right angle, one side vertical, one horizontal.

The solar unit is built up from a base plate, fitted to match the threaded studs. The unit is held in place, and is adjustable to exact parallelism with the vertical plane of the transit, by means of hexagon nuts which operate against the base plate at contact with the studs. There is provision to accommodate this fitting without undue strain, which is explained with the statement of making the adjustments.

The base plate supports the latitude axis, on which is mounted the latitude arc. That plate supports a cradle which carries the collar bearings of the solar telescope. The latitude vernier is attached to the base plate by separate mounting. The latitude clamp operates against the latitude axis, the tangent motion being secured from the base frame. The cradle is adjustable to make the line of sight of the solar telescope normal to the latitude axis.

The sun's light rays are picked up by a reflector which is placed at the objective end of the solar telescope. The declination arc is mounted on the tube of the solar telescope. The vernier arm is securely fitted to the reflector axis. The declination clamp operates against the reflector axis, with an arm which plays by tangent motion, the latter held in position by the mounting on the telescope tube.



A: The reflector axis, and coupling with the declination vernier-arm.

B: The declination clamp, and tangent-clamp-arm.

C: The frame, and reflector made from clear optical glass.

D: The declination tangent motion.

E: The cradle supporting the collar bearings of the solar telescope.

F: The latitude axis.

G: The points of adjustment on the base plate of the solar unit.

H: The latitude tangent motion.

J: The point of adjustment to make the line of sight of the solar telescope normal to the latitude axis.

K: The cover ring which protects the capstan screws of the reticle.

L: The hour circle.

M: The latitude arc.

N: The declination arc.

O: The declination vernier.

P: The latitude vernier.

Q: One of two opposing capstan screws in the declination tangent-clamp-arm, which control the adjustment to the zero position of the declination vernier.

R: The "dummy" screw in the declination vernier-arm, which is removed when using the adjusting post that is needed in making the latter adjustment.

There is an hour circle which is mounted on the tube of the solar telescope, near the eye-piece end, which reads at intervals of ten minutes from 6 a.m. to 6 p.m., apparent time.

Other important details of construction, designed for excellence in optical performance, and for exactness in accomplishing the adjustment, are explained in the statement of the latter steps.

The declination arc is graduated in half the normal interval, i.e. — a segment of 5° on the arc is graduated to read 10°. The vernier reads to single minutes, but it is usual to estimate the reading to the nearest half-minute. Note that the light rays from the sun are brought into the solar telescope by reflection, therefore a movement of 30″ in the reflector position gives a 60″ difference in the relation of the angle of incidence and the angle of reflection.

The equatorial lines are spaced at 15′45″ from the central line. This conforms with the sun's semi-diameter at the July 1 period, which is the minimum for the year. The maximum semi-diameter is reached about January 1 during which period it is 16′17″. At all times the overlap of the sun's image should be divided equally when making the solar orientation.

When set at maximum north or south declinations (23°26′) one end of the vernier will extend slightly beyond the end of the arc. During these periods caution is needed not to turn the solar telescope too far in hour angle, but to stop a little short of where the vernier would strike the latitude arc.

The Theory of Instrumental Orientation

The design of the solar unit is to provide a small-scale construction of certain arcs and lines which may be employed for instrumental orientation by bringing these into parallel with the elements that enter into the altitude observation on the sun for azimuth where the transit methods are employed.

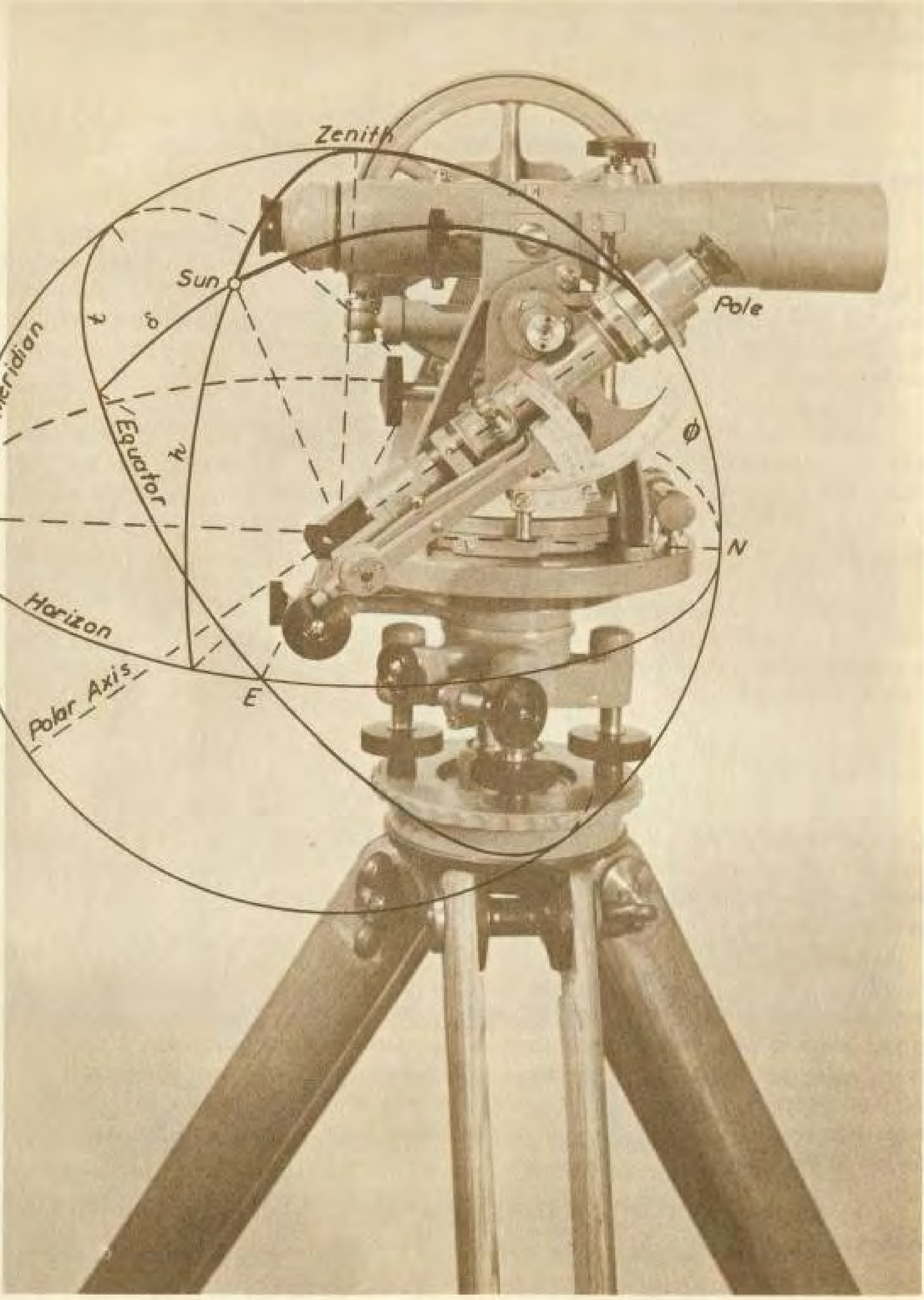
The latter requires the solution of the "pole-zenith-sun" triangle. There are three planes which create that celestial triangle. The intersections of the three planes at the point of observation create three lines. One is the vertical; one is the line to the pole; one is the line to the sun. The protection of the three planes into the celestial sphere creates three great circles, the arcs of which form the spherical triangle whose sides are from the pole to the zenith, from the zenith to the sun, from the sun to the pole.

The following equation will be found in the text books on applied field astronomy.

$$\text{Tan}^2 \tfrac{1}{2} A = \frac{\cos \tfrac{1}{2} (\zeta + \phi + \delta) \quad \sin \tfrac{1}{2} (\zeta + \phi - \delta)}{\cos \tfrac{1}{2} (\zeta - \phi - \delta) \quad \sin \tfrac{1}{2} (\zeta - \phi + \delta)}$$

From the above equation, another equation may be derived, which may be employed for the same purpose:

$$\text{Cos } A = \frac{\sin \delta}{\cos \phi \cos h} - \tan \phi \tan h$$


Zenith
Sun
Pole
Meridian
t
δ
Equator
h
ø
S
N
Horizon
Polar Axis
E

In both equations, the letters stand for the following elements:

A= Horizontal angle counting from the meridian. In the first equation, always from the north. In the second equation, from the north if the algebraic sign of the result is positive; it is from the south if the algebraic sign of the result is negative.

ζ (the Greek letter zeta) = zenith distance (90° — true vertical angle).

ϕ (the Greek letter phi) = latitude of the station.

δ (the Greek letter delta) = declination of the sun. In both equations the declination is treated as positive when in the north; negative when in the south; i.e. — in the first equation, change the sign for this element when the sun is in south declination. In the second equation, the fraction is given the negative sign when the sun is in south declination.

Memorandum: For observations in the southern hemisphere, the identical equations are employed, but the transpositions are needed as between north and south, and north declination and south declination.

h= The true vertical angle (90°-ζ) at the point of observation, counting to the sun's center. This is the observed vertical angle less the refraction in zenith distance, and plus the value of the sun's parallax.

The correction for parallax is to obtain a vertical angle equivalent to what would have been observed from a plane parallel to the horizontal plane at the transit station, but passing through the earth's center. It is 8.6" in vertical angle 15°, 4.4" at 60°; the value is disregarded in solar transit orientation.

The correction for refraction in zenith distance may be resolved into two parts, one the equivalent in the projection of that value on the line to the pole, called the refraction in polar distance. The second part is parallel to the equator. The latter being parallel to the equatorial wires of the solar unit, does not affect the solar

The value of the sun's refraction in polar distance for the time of the solar observation is added to the sun's computed north declination; it is subtracted from a computed south declination. The values are tabulated in the Gurley Ephemeris.

In normal solar transit practice, the sun's declination, corrected for refraction in *polar distance*, is usually computed or plotted in advance, in preparation for the day's work. These are the values that are set off on the declination arc when preparing for the orientation to the meridian.

In the theory of the solar unit, the three lines which are created by the intersections of the three planes of the "pole-zenith-sun" triangle, find a common intersection at the reflector of the solar unit. The line to the sun may be picked up when the sun's image is brought into the field of the solar telescope. The vertical line is created by the careful levelling of the transit. The line of collimation of the solar telescope is made to coincide with the line to the pole, when orientation has been accomplished, first setting the vertical angle of the solar telescope to agree with the latitude of the station.

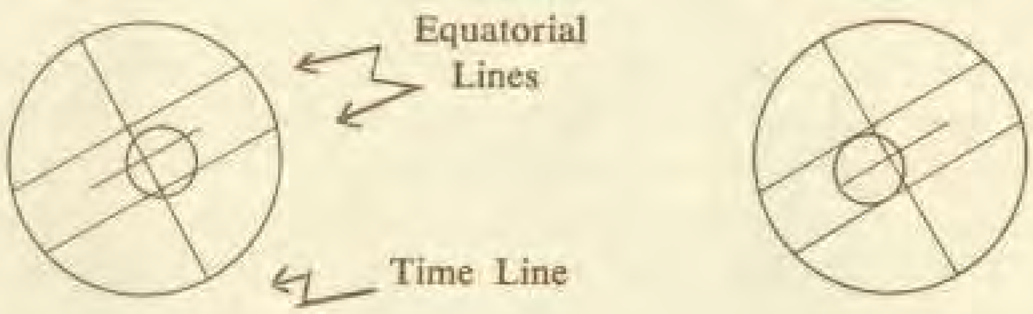
The steps for solar transit orientation at any station, stated in the terms ordinarily employed by the field party, are taken in the following order:

1. Level the transit and check the levels as needed.
2. Set the plates at zero, and clamp; lower clamp free.
3. Set the latitude, or correct by tangent motion for difference in latitude from the previous setting at the last station, as needed.

4. Set the declination, or correct by tangent motion for change in declination from the time of the previous setting, as needed.

5. Set the time circle for the approximate apparent time, rotating the solar telescope in its collar bearings for the hour angle from noon counting to the time of the observation. An exact setting in hour angle is not required. The approximate setting is needed to bring the sun's reflected light rays into the field of the solar telescope.

6. Next orient the transit to the meridan, or near the meridian, turning on the lower motion. Clamp the lower motion when the sun's image has been brought into the field of the solar telescope.



Not Oriented

When turning the transit in horizontal angle, the image of the sun cuts across the equatorial lines.

Oriented

The travel of the sun's image is along the path of the equatorial lines.

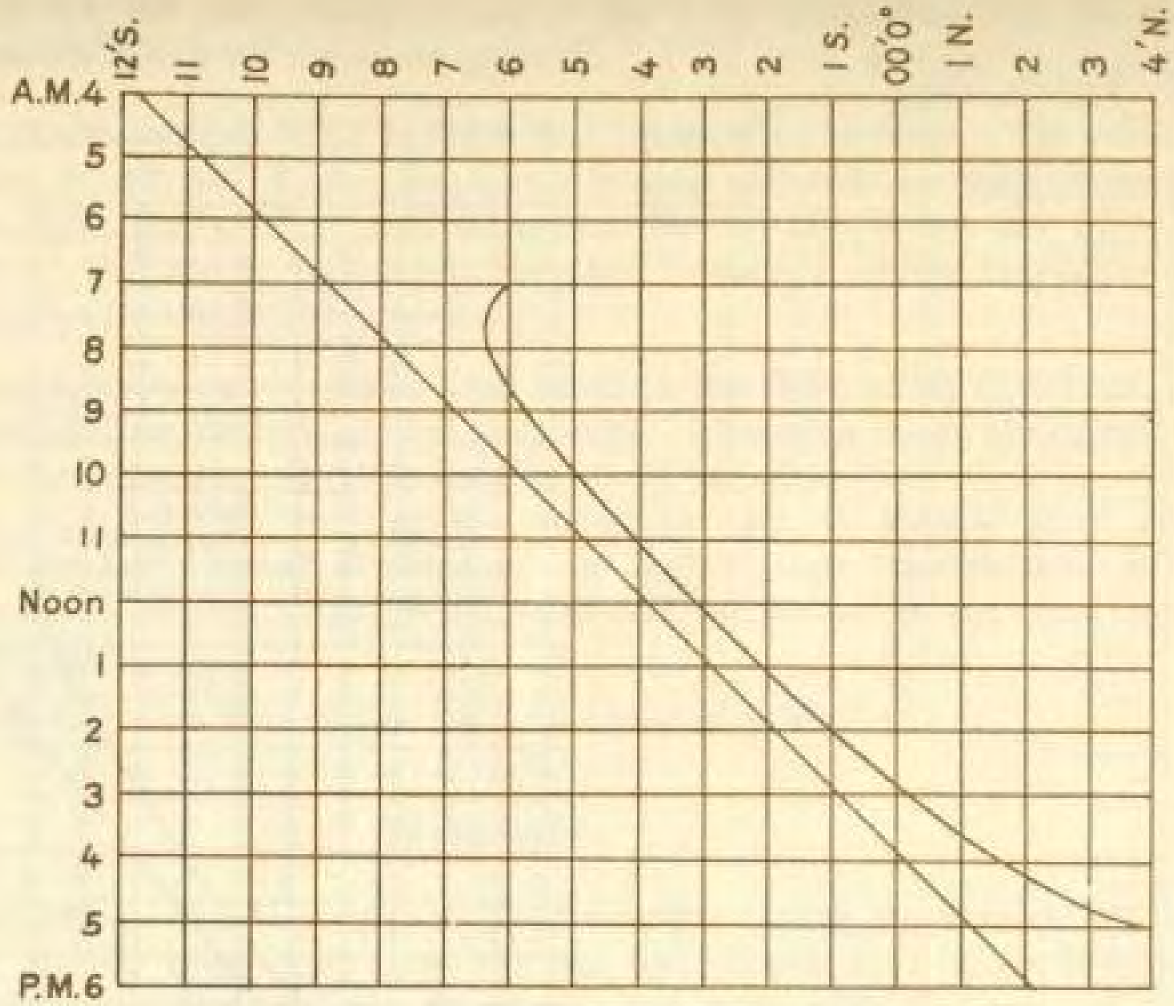
7. If needed, bring the sun's image to the middle third of the field by turning the solar telescope in hour angle; then, bring the sun's image accurately between the equatorial lines, using the lower tangent-motion of the transit.

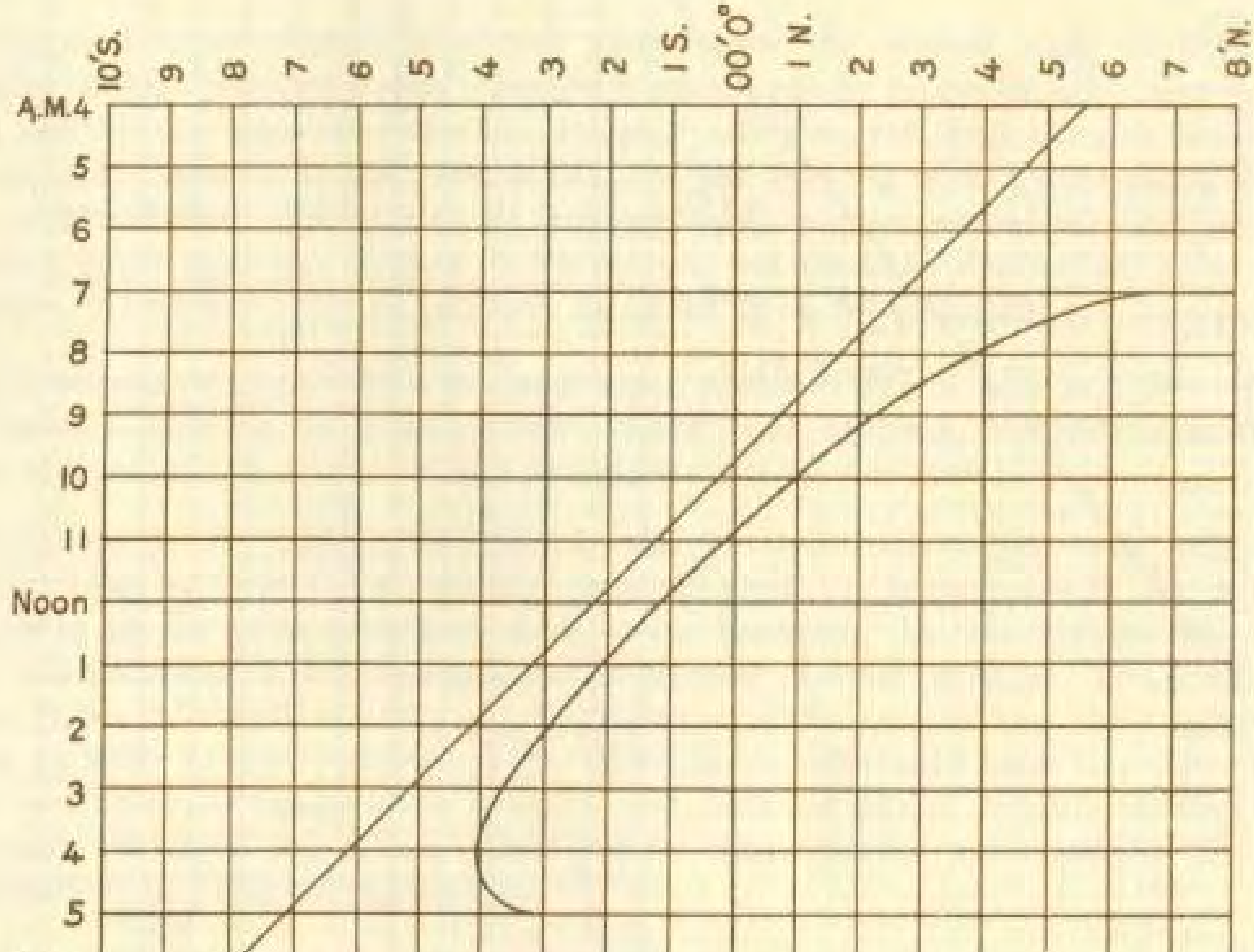
8. The last step accomplishes the orientation. All transit angles then count from the "solar meridian" as thus determined. Leave the latitude and declination arcs clamped, ready for use at the next station.

The Gurley Ephemeris contains examples of the method of computing the declination of the sun, including the preparation of a table for each hour of the day. Another plan for daily use is to plot the values on cross-section paper. See illustration page 11 for two dates, one when the sun is crossing the equator in northward change in declination; the second in southward movement.

First compute the declination for 7 a.m., apparent time. To that value add or subtract the change in declination for 10 hours, to give the 5 p.m. position. These two values are then marked on the cross-section. A straight line drawn through the two points; this line indicates the sun's true declination for the date.

The values for the refraction in polar distance are then scaled off always to the north, thus marking the points for a smooth curve which will give the settings in declination that are to be employed with the solar unit. If an altitude observation is made during the day, the value for the sun's declination at that moment should be taken from the straight line.


12'S.
11
10
9
8
7
6
5
4
3
2
1 S.
00'0°
1 N.
2
3
4'N.
A.M.4
5
6
7
8
9
10
11
Noon
1
2
3
4
5
P.M.6


10'S.
9
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8'N.
A.M.4
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Noon
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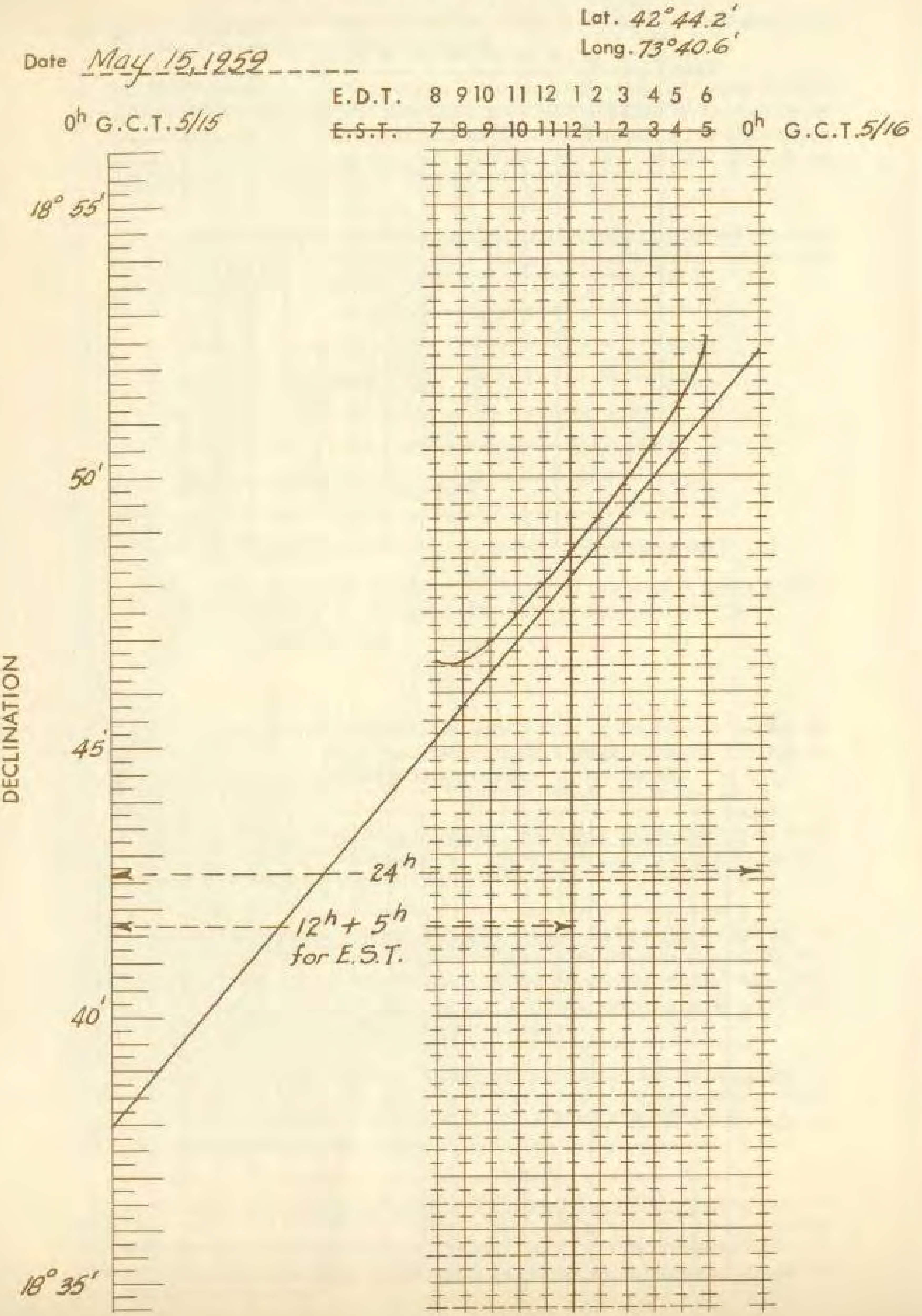
P.M.6

TELESCOPIC SOLAR DECLINATION SETTING



A quick, easy way of determining values of the sun's declination may be made using cross-section paper as shown on page 12.

The horizontal scale is laid off so each division represents one hour. The value of the declination for 0^h G.C.T. for the date is plotted vertically on the left and 24 hours to the right, the value of the declination for 0^h G.C.T. for the following date is plotted. A straight line drawn between these two points represents the declination change for the 24 hour period.

A vertical line is drawn to represent local noon to the right of 0h G.C.T. at 12h plus the Standard Time difference from Greenwich. Forenoon hours are designated to the left of the noon line and afternoon hours to the right.
Refraction is plotted to the north of the declination line, an amount taken from the tables for the Latitude and Declination. A smooth curve through these points makes it possible to take off values to set on the declination arc of the solar transit through out the day.

Note that unused lines on the cross-section paper have been omitted.

Orientation

The solar transit may be employed for orientation during the same hours during which an altitude observation upon the sun for azimuth may be made with a proper regard for the sun's position in altitude and hour angle.

Note that the corrections for refraction are quite large when the sun is near the horizon, and changing rapidly; there is also the uncertainty of the basic values during this period, frequently with considerable correction for temperature and barometric changes. The beginning point in the morning, or the stopping point in the afternoon, for reasonable precision in orientation, is at about 15° in the sun's altitude. However, as may be needed for short lines of less assured accuracy, the orientation may be accomplished during the lower altitudes.

The altitude observation is seldom made above the vertical angle of 60°, as the figure of the "pole-zenith-sun" triangle becomes poorly proportioned. The solar transit orientations may be continued at higher altitudes, but with caution, depending upon the exactness of the adjustments, and the showing of the solar orientation on the test meridian. The period of caution begins at about 10:15 to 10:30 a.m., depending much upon the latitude of the station, and the sun's declination. Correspondingly, orientation may be resumed at about 1:30 to 1:45 p.m.

The tolerance, as permitted in construction specifications, is held to 1'30". The solar transits most perfectly constructed, fitted, and adjusted, skillfully operated, should hold to within 1' of the true meridian most of the time.

Supplemental to good general adjustment, the uniformity of the solar orientation from hour to hour during the day depends upon the smoothness of the fitting and turning of the solar telescope in its collar bearings. In this construction the cradle and yolk blocks are equipped with enclosed resistent springs. The opening for the yokes is placed at the top; the design of the bearings and the mounting similiar to those of the Wye-level. The bearings are lubricated with a non-flowing grease unaffected by temperature changes, and intended not to require cleaning or replacement during a full season's field work. The bearings are protected by felt grease-washers and dust-proof housing.

The sun's declination corrected for refraction in *polar distance*, is usually computed or plotted in advance, in preparation for the day's work.

In the operation of the solar transit, the latitude and declination arcs are left clamped after making the initial settings each day. The changes in latitude from station to station on a north and south line, or for northing or southing on any traverse line, are taken care of by the tangent motion. The changes in declination from hour to hour during the day, should be noted constantly, and taken care of by the tangent motion. The same settings are employed in moving from station to station, excepting to correct for the changes in latitude and declination as noted, and a check to make sure that the readings of the arcs have not been disturbed.

No back sights are employed, usually, where the line runs through timber or undergrowth, granting that the solar unit is in good adjustment, and is being used for orientation during the same hours when the sun may be observed in vertical angle for azimuth by normal transit methods.

On traverse lines and when making offsets to avoid obstructions, the survey may proceed by occupying each alternate station.

On east and west lines, and on traverse lines generally there is no correction for convergency or curvature, or correction between forward azimuth and back azimuth. All directions of lines are recorded at once in terms of angular measure counting from the true north or south at the station of record, and within the limit of accuracy attainable by solar transit orientation. This is slightly better than 1:2000 when the limiting tolerance is not over 1'30".

When an accuracy better than 1:2000 is required, other approved transit methods should be employed for the azimuth determinations, especially checking the longer open sights. On the latter class of surveys the solar unit may be used where most important for the time saving on short offsets, and in getting around difficult obstructions or objects that can not or should not be removed.

Where the solar unit is employed exclusively as in running through timber and undergrowth, the forward sights are usually short, with just enough cutting to secure proper alignment, usually insufficient for running by back sight. There may be from 20 to 30 or more set-ups to the mile, each on solar orientation. The result, in effect, for the direction of the established line is the mean of the whole number of solar orientations.

When changing to the normal transit methods for the more refined observations and for the verification of the orientation by the solar unit, note that the reticle of the transit telescope provides a "solar circle"; this is to secure exact coincidence in horizontal and vertical angle readings when making an altitude observation on the sun for azimuth. The solar circle aids materially in making the altitude observation, reducing the amount of time in accomplishing coincidence. All readings count to the sun's center, making the data for each observation complete in itself.

An Historical Sketch

Since our organization in 1845, W. & L. E. Gurley has designed and constructed every type of instrument that has been required in the subdivision of the vast area of the United States public domain. Many of the same instruments have been supplied to engineers engaged in general surveying practice in North and South America, and the Orient.

The rectangular surveying system, which was originated in the United States, has been applied throughout the public domain. The controlling lines have been established on cardinal courses. The directions of all lines of the minor subdivisions have been defined in terms of angular measure referred to the true north and south at the point of record. The principal control has been the survey of standard parallels of latitude and guide meridians, usually spaced at intervals of twenty-four miles. The smaller subdivisions are the townships six miles square, and the sections one mile square.

The rectangular plan was first established over all of what was called the Northwest Territory, and the areas of the South which were ceded by the Colonial States to the Federal Government. The same plan, with gradual improvements in the technique of making the surveys, has been extended over the great additions to the public domain which were acquired through the Louisiana purchase, and the lands ceded to the United States by Spain, Mexico, the Republic of Texas, Great Britain, and Russia. All of this required the adaption of the rectangular plan to the spheroidal form of globe. The imperative need has always been for accurate instrumental orientation for the running of the lines of the meridian and the parallels of latitude. Emphatically, the problem has been one of large scale surveying, with the refinements in geodesy suited to the figure of the earth. This has attained a high practical development in the use of the solar transit.

In the early land-surveying practice of the *Colonial area*, i.e. — the States of the Atlantic seaboard, the principal instrument was the needle compass; the lines were usually run on irregular courses, with descriptions by metes-and-bounds. It was usually *intended* to orient first by reference to the magnetic north, then turning off the magnetic declination, so that the record courses could be expressed in true bearings. The same plan of orientation was applied in the early public-land surveys, but the inaccuracies of needle courses was a serious handicap to the rectangular plan when applied on a large scale. Its use had to be discontinued in the upper regions of the Great Lakes, and in all other areas where magnetic ore deposits made the needle more than ordinarily unreliable.

Evolution of the Solar Unit

The Burt solar compass was introduced in Northern Michigan about 1836, and was found to be thoroughly well suited to the requirements. It was widely used for many years throughout the public domain, both in the forest areas and on the prairies. Its great importance was due to the accurate instrumental orientation, and that the east and west lines through the forest could be run as true lines.

The transit construction became necessary in the rough mountain areas of the western portions of the public domain. The first type was the Burt design of a solar unit, mounted upon the telescope of a Gurley transit. This was a long step forward in instrumental design, both for accuracy and general usefulness. This instrument was extensively used on the public land and mineral surveys of the west.

Beginning with 1920, W. & L. E. Gurley has been making a telescopic solar unit, mounted on the standard to afford the advantages of good optics suited to solar observations, and the special arcs for setting off the latitude and the sun's declination, so as to operate entirely apart from the main telescope and circles. This has made for greater accuracy in solar orientation, increased dependability, and has very much reduced the time that is required in making the solar observation. In fact, it might be stated that, after the transit set-up and levelling, and after having made the initial settings of the latitude and declination for the day's work, the solar orientation scarcely takes any time at all.

Modern Developments

In the planning of the improvements, the Gurley engineers, opticians, and instrument designers have constantly studied the more exact methods of construction, operation, and the making of the adjustments and tests, always bearing in mind the general usefulness of the solar transit, including the larger field of land surveying in all of its many branches. The modifications in design have been made to improve the accuracy and dependability, in this problem disregarding the heavy expense of making the changes in the patterns. Our latest solar transit is the most complete and best instrument that has ever been made available for land surveying, to give rapid and accurate instrumental orientation, at the same time adding all detail requirements for the modern methods in the making of stellar observations. As a complete operating unit it has no worthy competitor when employed as a land surveying instrument.

The contributors to the preparation of this bulletin have both had many years practical and successful field experience in the use of the solar transit, covering many thousands of miles of actual line running, performed personally under all conditions of terrain, forest cover, undergrowth, and season, including field use of other well-known solar units. Both have made many valuable suggestions in planning the improvements, now finding expression in the Gurley No. 112 - RT.

Methods of Test, Testing Station and Establishment of Meridian Line

July 24, 1946, at the testing station, "Troy Cabin", in latitude 42°44′03″N., and longitude 73°35′15″W.; an observation at apparent noon to test the reading of the declination arc; an orientation with the solar unit at 4^h24^m p.m., app.t., to test the indication by comparison with the true meridian as established by independent observations on Polaris, several equatorial stars and the sun. The observing line is about 1600 ft. long. The testing station is in the country outside of Troy and is free from any local magnetic disturbances. Gurley No. 112-T, 461255, as follows:

The sun's declination at apparent noon, 19°54′40.7″N., refraction applied; at 4^h24^m p.m., app.t., 19°53′05.4″N.

At apparent noon, with the latitude arc set at 42°44′N.; the transit oriented to the meridian; bring the sun's image into position by the declination tangent-motion; the reading of the declination arc is 19°55′N., which agrees with the computed declination.

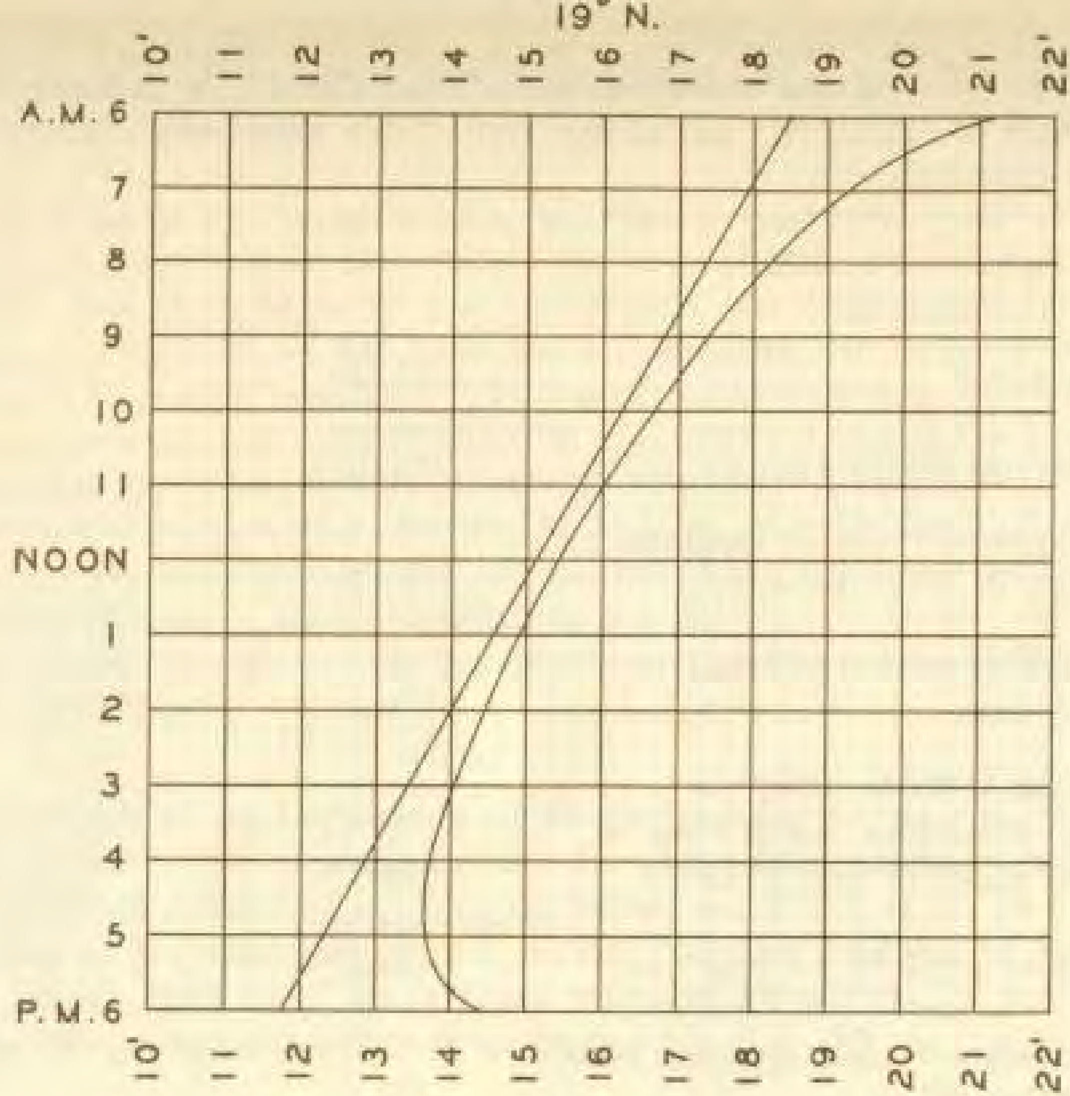
At 4^h24^m p.m., app.t., with the latitude arc set at 42°44′N.; the declination arc set at 19°53′N.; orient the transit with the solar unit; on this test the transit telescope intersects the meridian.

At the latter time the magnetic declination reads 13°44′W.

July 27, 1946, at the testing station, "Troy Cabin", in latitude 42°44'03"N., and longitude 73°35'15"W.; an all-day test of the solar unit; Gurley No. 112-T 461255, as follows:

The sun's declination at 0^h00^m Greenwich civil time		19°24'38.7"N.
Difference for 1^h	—33.66"	
Diff. in time to 7^h00^m a.m., Gr.	$7^h00.0^m$	
Add difference to 7 a.m. in longitude of station, or local mean time	4 54.3	
Equation of time to be added to apparent time 6^m22^s	6.4	
Elapsed time from G. 0^h00^m to $7^h06^m22^s$ a.m., local mean time, or $7^h00^m00^s$ apparent time (12.01^h)	$12^h00.7^m$	
Diff. in decl. = 12.01 x 33.66" =	404.3"	6'44.3"S.
Sun's declination 7 a.m., apparent time		19°17'54.4"N.
Difference for 10^h	336.6"	5'36.6"S.
Sun's declination 5 p.m., apparent time		19°12'17.8"N.

At apparent noon, with the latitude arc set at 42°44'N.; the transit orientated to the meridian; bring the sun's image into position by the declination tangent-motion; the reading of the declination arc is 19°15'30"N., which agrees with the computed declination.



July 27, 1946, same station: Tabulation of the direction of the line as determined by the orientation of the solar unit, and compared with the established meridian; Gurley No. 112-T 461255:

Time	Latitude	Declination	Orientation Solar Unit	Mag. Decl.
7:30 a.m., app.t.	42°44′N.	19°19′00″N.	Meridian	14°12′W.
8:30		19°18′00″N.	Meridian	
9:00		19°17′30″N.	N.0°00′20″W.	14°16′W.
10:00		19°17′00″N.	Meridian	
10:30		19°16′30″N.	N.0°00′20″E.	14°10′W.
1:40 p.m. app.t.		19°14′30″N.	N.0°00′20″E.	
2:15		19°14′30″N.	N.0°00′30″E.	14°05′W.
2:55		19°14′00″N.	Meridian	
3:45		19°14′00″N.	Meridian	14°05′W.
4:30		19°14′00″N.	Meridian	
5:00		19°14′00″N.	N.0°00′30″W.	13°55′W.
5:40		19°14′00″N.	N.0°00′30″W.	
6:00		19°14′00″N.	Meridian	

Altitude Observation on the Sun for Azimuth

The performance of the solar unit may be verified on any survey, even remote from an established meridian, by making use of the transit for a direct altitude observation on the sun or comparison. The horizontal angle in such a test would be turned from a point on any desired line whose direction had been observed with the solar unit. The following example brings out the capabilities of the transit in this respect, and the technique of good coordination.

July 27, 1946, at the testing station, "Troy Cabin", in latitude 42°44′03″N., and longitude 73°35′15″W.; an altitude observation on the sun for azimuth, Gurley No. 112-T 461255, as follows:

Tel.	Watch a.m.	Hor. Ang. from North.	Vert. Ang.	Declination
Dir.	$6^h58^m47^s$	83°33′00″	22°01′00″	
Rev.	7 02 57	84 13 30	22 46 00	
			v = 22°23′30″	19°18′00″N.
Mean	$7^h00^m52^s$	83°53′15″	r = — 2 20	
			Par. = + 08	
			h = 22°21′18″	
	p.m.			
Dir.	$5^h12^m06^s$	84°42′00″	23°10′00″	
Rev.	5 15 12	84 13 00	22 36 30	
			v = 22°53′15″	19°12′17″N.
Mean	$5^h13^m39^s$	84°27′30″	r = — 2 20	
			Par. = + 08	
			h = 22°51′03″	

$$\cos A = \frac{\sin \delta}{\cos \phi \quad \cos h} - \tan \phi \quad \tan h$$

a.m. cos nat	sin	tan	p.m. cos log	sin	tan
ø = 0.73451		0.92388	9.865998		9.965615
δ =	0.33051			9.517123	
h = 0.92484		0.41125	9.964504		9.624700
Prod. 0.67930	0.67930	0.37995	9.830502	9.830502	9.590315
Frac.	0.48654			9.686621	
			nat	0.48598	
	0.37995			0.38933	0.38933
Diff.	0.10659 (+)			0.09665 (+)	
cos A = 0.10659			0.09665		
A =	N.83°52′52″E.			N.84°27′13″W.	
Hor. Angl.	83 53 15			84 27 30	
	N.00°00′23″W. a.m.			N.00°00′17″E. p.m.	
				N.00 00 23 W. a.m.	

Indicated bearing of meridian mark = N.00°00′03″W.

Adjustments of the Gurley Telescopic Solar Unit

W. & L. E. Gurley Model No. 112-T Telescopic Solar Transit. Conforming with General Land Office specifications dated June 10, 1944. Construction as completed and accepted June 21, 1946.

An abbreviated statement of the field adjustments and tests, prepared as a *substitute* for the instructions issued by the makers for Model No. 92 Hell Gate Precise Telescopic Solar Transit, 1937.

In this form the instructions are principally for engineers already familiar with solar transit construction, and primarily to supply the information regarding the special features of the new Model No. 112-T.

Arthur D. Kidder
District Cadastral Engineer

Transit adjustments: Care should be taken to ascertain that the transit adjustments are in good order before attempting to bring the solar unit into parallel with the vertical plane of the transit telescope. Note that the sighting of the transit telescope in the true horizontal plane is depended upon in making certain adjustments of the solar unit.

Both the transit and solar unit have been placed in good adjustment and fully tested prior to the shipment of the instrument from Troy, N. Y. The verification in the field is to guard against possible disturbances in shipment, and to note and correct the residual errors which are liable to be found in a new instrument until the stresses and strains of adjustment have become stabilized.

The necessary preparations at the testing station are described in the explanation of the adjustments Nos. 4, 5, 6, 7, and 8. The transit is to be carefully levelled when taking the several steps.

1. *Focus of the solar telescope:* The eye piece is focussed on the cross wires by rotating the knurled rings nearest the eye; the eye piece turns freely, and has a pin which travels in a guide slot; this pin is not a clamp. After securing a sharp focus on the cross wires, bring the objective into good focus on the sun. The outer ring of the sun should be clean cut and sharp; if there are sun spots in the field at the time, these should be distinct and plainly visible. The objective may be moved by first loosening, then pushing the screw, which will be found to travel in a guide slot near the lower (or left hand) collar bearing. The celestial focus should be fixed in position by tightening the adjustment screw.

2. *Equatorial wires parallel to axis of reflector:* Bring the sun into the field of the solar telescope as in normal orientation. This requires setting the latitude of the station, the sun's declination for the date and hour, the hour angle for the apparent time, then orient to the meridian. This brings the reflected image of the sun between the equatorial wires. Turn the solar telescope back and forth in hour angle, that is by turning the telescope in its collar bearings. If in good adjustment the sun's image should follow the equatorial wires from side to side of the field.

If not in good adjustment, the solar cross-wire assembly, or reticle, will require a slight rotation to bring it into good position. In this test; if the sun's image departs materially from the equatorial wires in the travel across the field, the capstan screws which hold the reticle should be loosened, and the reticle rotated as needed to bring the wires into good position; then return each capstan to a proper seat. This will always require a check of the collimation adjustment. There is a cover ring which protects the capstan screws; the cover ring screws back over the eyepiece tube.

3. *Collimation of the solar telescope:* Make a direct sighting of the solar telescope on a distant point, and tighten all clamps.

Note that the reflector is constructed of clear optical glass, the planes truly parallel, and duly tested. Note also that the clear glass, and the rectangular form, afford the full use of the solar objective in any position of the reflector. Loosen the declination clamp, then turn and clamp the reflector at 90° to the line of sight (good vision may be secured at other angles without apparent displacement).

Use a transit tangent motion to set in horizontal angle; the latitude tangent motion for setting in vertical angle. Turn the solar telescope 12 hrs. or 180° in hour angle. The displacement of the sighting point, if any, on reversal, is double the error in collimation, in both directions, — for the equatorial wires, and for the time wire. If the line of sight remains fixed on the sighting point it agrees with the turning axis as required.

If after revolution, the line of sight appears to be above or below, or to the right or left of the sighting point, one-half of each difference should be taken up with the capstan screws. As noted above, there is a cover ring which protects the capstan screws; the cover ring screws back over the eye-piece tube.

The collimation adjustment is very important to the correct operation of the solar unit, and should be carefully repeated when adjustment is required. When accurately accomplished it should hold well. The test and adjustment is similar to collimating the telescope of the Wye-level.

As the eye-piece of the solar telescope gives an inverted image, the direction for the movement of the reticle to correct for collimation is *apparently to reduce* the error, i.e. — if there is appreciable displacement, turn the capstan screws so as to move the reticle in the direction towards the image of the sighting point, both vertical and horizontal. The correction is for *only half the amount* of the displacement.

4. *Line of sight normal to the latitude axis:* This adjustment is accomplished in a manner similar to making the collimation adjustment of the transit telescope, and may employ the same points forward and back if clear visibility can be secured through the solar telescope. Excellent sighting points may be established with lath painted white, or covered with a white cloth, placed up to 1000 or 1500 ft. distant, with low or zero vertical angle, carefully established for alignment.

The instrument is to have an offset at the transit station to place the solar telescope in the line of the test. Make a direct sighting of the solar telescope on one of the sighting points, and tighten all clamps. Reverse the solar telescope on the latitude axis to pick up the sighting point in the opposite direction, and again tighten the latitude clamp. If the line of sight does not intersect the sighting point, the correction will be for *one-half* the difference.

The adjustment is secured through the movement of three capstan head screws, which are placed at the eyepiece end of the cradle that supports the solar telescope. There is provided a rocking-bar at the opposite end of the cradle to avoid any strain that might otherwise be carried to the collar bearings. There are three capstan screws to hold the adjustment. These screws are used to move the solar telescope in or out from the cradle. To move the solar telescope in toward the cradle, loosen the two outside capstan screws and tighten the center capstan screw. To move in the opposite direction reverse the above procedure, secure a careful adjustment, repeating the test on the forward and back sights. When seating the capstan screws care should be used to apply equal pressure.

As the eyepiece of the solar telescope gives an inverted image, the *direction* for the movement is *apparently to increase* the error, i.e. — on the reversal, if the image of the sighting point appears to be on the left then actually the line of sight is in error to the left, and the control point adjustment (the three capstan head screws) should be corrected so as to move the line of sight to the right in one-half the amount of the apparent error. On the reversal, if the image of the sighting point appears to be on the right, the adjustment should be corrected so as to move the line of sight to the left, apparently away from the image, and in one-half the amount.
Note: The above instructions for adjustment Number 4 apply to solar transits manufactured subsequent to 1955. For instruments supplied prior to that time write to W. & L. E. Gurley, Troy, N. Y.

At the conclusion of the 4th adjustment it is advisable to make a preliminary test for parallel sighting at horizontal (7th adjustment). If there is a large discrepancy it should be removed at this stage. If the error is small it is better to make the final correction in the order that follows. The test is made by sighting both telescopes to points having the offset employed in this the 4th adjustment.

5. *Zero position of the declination vernier:* Next, after completing the 4th adjustment as described, while in the same offset, turn the transit 90° in horizontal angle, and clamp the solar telescope in zero latitude. This brings the reflector into the line of the test. Set the zero of the declination vernier at the zero of the declination arc, in which position the reflector should be at 45° to the line of the test.

Note that the placing of the clamp at the reflector axis is an important new feature. The design is intended to avoid the strain and displacement in the clamping that may result in the older models, where the clamp was placed on the arc, in case of imperfect fitting or worn parts of the declination-clamp assembly. Note also, that the vernier graduations have been made directly on the vernier arm, and that the declination arc is secured in radius and concentric position with the vernier and the reflector axis with no provision for shifting any of these parts.

First pick up the reflected image of one of the sighting points. Turn the solar telescope in hour angle as needed, above the 6 a.m. or 6 p.m. position for whatever vertical angle there may be in the line to the sighting point. Bring the central equatorial wire onto the image of the sighting point by a transit horizontal tangent motion. The next step is to turn the solar telescope in its collar bearings 12 hrs. in hour angle, or as needed, to pick up the second sighting point. If the central equatorial wire is on the image of this sighting point all conditions are satisfactory, i.e.— the zero position of the declination is correct, meaning no index error in this portion of the declination arc.

If the central equatorial wire is not on the image of the second sighting point, the difference is double the index error at zero. In proceeding with this determination, correct half the difference on the declination tangent motion, half with a transit horizontal tangent motion. Repeat the reversals of the solar telescope in hour angle, and the half-and-half corrections as needed, until both positions are coincident. This brings the reflector into exact 45° angle with the sighting line. The vernier reading is then the index error for that portion of the declination arc. A small index error should be noted as a matter of record. A supplemental test by noon observation is always required in that portion of the arc which will be employed for the period of use.

Note that in picking up the reflected light rays, the direct light rays must be excluded, and that it is exceedingly helpful to shade the whole instrument and the observer's eyes. A black umbrella is very satisfactory for this purpose.

If the reflector position has been disturbed, or the reflector assembly has had to be removed or taken apart for any purpose, the exact position may be recovered as described. The setting may be corrected at the reflector axis, where the declination-vernier arm is locked in position by three set screws. To accomplish this adjustment the reflector and the tangent-clamp arm are to be left clamped in the exact 45° position.

The first step in making the adjustment is to loosen the three hold-down screws, just enough to allow the declination-vernier arm to be shifted. The reflector position is not disturbed. Next, remove the "dummy" screw that is placed about mid-point of the arm, and in its place insert the special adjusting post (the latter will be found inserted, for safe keeping, near the top of the right standard of the transit). When in position the end of the post projects into a hole in the tangent-clamp-arm. There are two opposing capstan screws in the tangent-clamp-arm which are to be brought into play against the adjusting post.

The parts are now in position for an exact setting of the vernier to zero reading on the declination arc. Two capstan pins are used in opposing movement to accomplish the exact adjustment.

After adjustment, tighten the three hold-down screws at the reflector axis. Repeat the original test to make sure that the declination clamp held properly during the adjustment, and that the reflector position was not disturbed from any cause. Back off the two opposing capstan screws. Remove the special adjusting post. Replace the "dummy" screw. Replace the adjusting post for safe keeping. Tighten the two capstan adjusting screws to avoid loss.

6. *Latitude axis in horizontal position:* After completing the 4th and 5th adjustments, and with the declination vernier remaining clamped in the zero or exact 45° position, the next step is to check, and, if needed, to make the adjustment to bring the latitude axis into true horizontal.

Bring the solar telescope into vertical, corresponding to 90° latitude, eye-piece end up, and the telescope turned in its collar bearings to the 6 a.m. position.

A horizontal line in the exact H. I. of the reflector as thus placed is required for this test. The elevation should be determined with care. The mark, line, level-rod target, solar diagram, or pattern may be located in horizontal in any distance from 300 to 600 ft. Having carefully levelled the transit, orient with the reflector towards the testing sight.

Unless the set-up is quite low, the observer may need to stand on a small block in order to look down into the solar eye-piece. Provide the shading as suggested for the 5th adjustment.

When the latitude axis is in true horizontal, the central equatorial wire should pick up the image of the sighting mark, line, level-rod target, solar diagram or pattern as described above. If adjustment is required, it is controlled on the solar unit base plate, at the upper foot post.

Opposing hexagon nuts are provided, in the assembly of which counter-sunk ball-shaped units are inserted to accommodate an adjustment of the three-point base. Caution is required, however, in making the adjustments on the foot posts to ease the pressure at all three posts, and to restore equal seating pressure all around.

It is advisable to check the 7th adjustment (parallel sighting at horizontal) while making the 6th adjustment, and to bring both foot-post corrections along together.

Alternate method. If a separate check is desired, the solar telescope may be used for a direct sighting on a vertical line, as in the adjustment of the standards of the transit telescope. On a short distance to the vertical line it will be necessary to bring the solar objective into good focus, to be carefully restored to celestial focus when the check has been completed.

7. *Parallel sighting at horizontal:* If adjustment is required, it is controlled on the solar unit base plate, at the lower left-hand foot post.

There are several different positions in which this test may be made, the first mentioned with the explanation of the 4th adjustment (line of sight normal to the latitude axis). Another position is to employ a sky-line object so far distant that the offset between the transit and the solar telescopes may be disregarded.

If the 6th adjustment (latitude axis in horizontal) is accomplished by the *alternate method* as explained, it is best to provide two points or lines in horizontal elevation with the transit, having the identical offset of the two telescopes, in order to make the 6th and 7th adjustment together or combined, as either one may effect the other, and it is necessary to stabilize the 3-point contact positions on the base frame of the solar unit.

The preferred method for the 6th adjustment was described first. In that position it is desirable when elevating the solar telescope to zero latitude (or low vertical angle) to have two sighting points in that direction for the test of the parallel sighting at horizontal. This is to make it convenient for the observer to check from one to the other position (6th and 7th adjustment) without anything more than just to move the solar telescope in vertical angle, and possibly a slight use of a transit horizontal tangent motion. The two sighting points or lines in near horizontal are to have the identical offset of the transit and solar telescopes, and should be sufficiently distant that no change in focus of the solar telescope is required (300 to 600 ft.). The two sighting points in near horizontal will be in the line of the direct sighting of the solar telescope when set at or near zero latitude, the line being 90° (± the transit horizontal-tangent-motion correction) in horizontal angle counting from the mark, line, level-rod target, solar diagram or pattern which may be employed in making the 6th adjustment. Where the site conditions at the field testing station are suitable, this makes the most satisfactory and refined arrangement for bringing the 6th and 7th adjustment along together.

8. *Zero position of the latitude vernier:* This determination should always be preceded by whatever corrections may be required in making the 6th and 7th adjustments, as the mounting of the latitude vernier is carried from the base frame of the solar unit. The latter, as well as the 8th adjustment, depend upon the correct optical performance of the solar telescope, accomplished in the earlier adjustments. The transit telescope is employed to determine the horizontal plane.

The test will be made on a horizontal line in the exact H. I. of the solar telescope. The test requires the careful levelling of the transit. As in making the 6th adjustment by the preferred method, the elevation should be determined with care. The test will be made on the same object employed in that adjustment, except for the difference in the H. I. position of the solar telescope. The sighting object may be any mark, line, level-rod target, solar diagram or pattern, located in horizontal in any distance from 300 to 600 ft.

Make a direct sighting with the solar telescope, hour-angle position 12 hr., or noon; use the latitude tangent motion to bring the central equatorial-wire on the sighting object. The reading of the vernier will indicate the index error in zero latitude.

As a rule it is better not to change the vernier setting if the fitting is good and only a small difference. If necessary, the vernier may be shifted to read zero. Caution is again mentioned here to see that the vernier ends are equally spaced from the arc for exact concentric position, close enough to read well, but the fitting should not bind or drag in the slightest.

Memorandum by the makers: In the collimator assembly-adjustments and tests of these solar transits, the latitude verniers were carefully set in zero position, then each arc was tested in the vertical angle 33°43′30″ to insure that no discrepancy existed as between those positions. The tests were entirely satisfactory within the limitation of exactness in the vernier readings. This series may be identified by the maker's serial numbers, as follows:

Delivered on the contract with the General Land Office:

461258	461263	461267
461260	461266	461268

For delivery elsewhere:

461254	461257	461261
461255	461259	

Note that the latitude clamp is placed so as to operate on the latitude axis. This enables the solar telescope to be clamped in any vertical angle, including the reversed positions. This construction avoids placing any side strain on the latitude arc, and the possible displacement caused by poor fitting or worn parts in the latitude-clamp assembly, as sometimes occurred in the older forms of construction where the clamp was placed on the arc.

9. *The noon solar observation:* An established meridian is required for this orientation, though not necessarily exact. A meridian by solar orientation as late as 10:30 or 11:00 a.m. may be employed where the adjustments are in fair order. In the noon test as recommended, *precision in latitude* is required within the limit of accuracy of setting the latitude vernier, i.e. — to the nearest 30″; a closer setting than that limit may be secured by practice and experience.

Shortly before apparent noon, orient the instrument in the established meridian, and set off the *known true latitude* ± the index error, if any, in the zero position of the latitude vernier. Set off the calculated declination of the sun for the apparent noon of the date, corrected for refraction. Carefully maintain the transit levels during the period of the observation.

Follow the sun's travel by movement of the solar telescope in hour angle, bringing the sun's image accurately between the equatorial wires by the *declination tangent-motion.* A number of readings may be made, if desired, during a period of twenty minutes or more. The difference between the reading of the declination arc, or the mean of several readings, and the calculated declination (corrected for refraction as noted) will indicate the index error in declination in that portion of the arc. The test should be made daily when the solar transit is in use. The value to be employed in the solar orientation is the index correction that has been determined in that portion of the arc where being used.

Note that in the construction of the declination tangent motion, the tangent screw and the opposing spring with its housing are interchangeable in position. In north declination it is better to have the tangent screw towards the south end of the arc, changing to the north end after the sun passes into south declination.

10. *The hour circle:* The graduations on this circle are made at intervals of ten minutes in time. The readings, in apparent time, may be made to within two or three minutes, which is good for reference in setting the declination and for setting the solar telescope in hour angle to bring the sun into the field when making the solar orientation.

The hour circle is held in position by a set screw. The circle may be shifted, if needed, so as to read 12 hours at apparent noon. That is the best time, and the best method for making the setting. Elevate the main telescope in the meridian at the vertical angle to agree with the sun's position for the date. Turn the solar telescope in hour angle as the sun travels into and across the field of the *main telescope*. Bring the sun's image to the center of the field of the telescope as determined by the time cross-wire at the moment of the sun's meridian passage.

Stop turning the solar telescope in hour angle at the moment when the exact meridian passage is noted in the main telescope. Then, without disturbing the solar telescope in hour angle, shift the hour circle to read 12 hours, or apparent noon.

The test may be repeated, as desired, by setting the watch to read twelve at apparent noon, or by noting the watch correction in terms of apparent time, and later checking the reading of the hour circle when making a solar orientation.

Orientation

The general adjustments are designed for the instrument assembly in the beginning, and after repairs have been made, or in remounting the solar unit if it has been removed. The general adjustments give attention to the correct relation of all working parts, good for any latitude.

The solar orientation to the true meridian should be satisfactory when each required adjustment has been carried through successfully, including the determination of index error, if any, to be applied in making the settings for latitude and declination.

At this point the solar unit is ready for p.m. and a.m. tests for orientation by comparison with a carefully determined meridian, the meridian mark being established by approved methods, and itself being duly checked in the event of too large a discrepancy in relation to the orientation of the solar unit.

The tolerance, as permitted in construction specifications, is held to 1'30". The solar transits most perfectly constructed, fitted, and adjusted, skillfully operated, should hold to within 1' of the true meridian most of the time.

Supplemental to good general adjustment, the uniformity of the solar orientation from hour to hour during the day depends upon the smoothness of the fitting and turning of the solar telescope in its collar bearings. In this construction the cradle and yoke blocks are equipped with enclosed resistent springs. The opening for the yokes is placed at the top; the design of the bearings and the mounting similar to those of the Wye-level. The bearings are lubricated with a non-flowing grease unaffected by temperature changes, and intended not to require cleaning or replacement during a full season's field work. The bearings are protected by felt grease-washers and dust-proof housing.

The sun's declination corrected for refraction in *polar distance*, is usually computed or plotted in advance, in preparation for the day's work.

In the operation of the solar transit, the latitude and declination arcs are left clamped after making the initial settings each day. The changes in latitude from station to station on a north and south line, or for northing and southing on any traverse line, are taken care of by the tangent motion. The changes in declination from hour to hour during the day, should be noted constantly, and taken care of by the tangent motion. The same settings are employed in moving from station to station, excepting to correct for the changes in latitude and declination as noted, and a check to make sure that the readings of the arcs have not been distured.

No back sights are employed, usually, where the line runs through timber or undergrowth, granting that the solar unit is in good adjustment, and is being used for orientation during the same hours when the sun may be observed in vertical angle for azimuth by normal transit methods.

On traverse lines and when making offsets to avoid obstructions, the survey may proceed by occupying each alternate station.

On east and west lines, and on traverse lines generally there is no correction for convergency or curvature, or correction between forward azimuth and back azimuth. All directions of lines are recorded at once in terms of angular measure counting from the true north or south at the station of record, and within the limit of accuracy attainable by solar transit orientation. This is slightly better than 1:2000 when the limiting tolerance is not over 1'30".

When an accuracy better than 1:2000 is required, other approved transit methods should be employed for the azimuth determinations, especially checking the longer open sights. On the latter class of surveys the solar unit may be used where most important for the time saving on short offsets, and in getting around difficult obstructions or objects that can not or should not be removed.

Where the solar unit is employed exclusively as in running through timber and undergrowth, the forward sights are usually short, with just enough cutting to secure proper alignment, usually insufficient for running by back sight. There may be from 20 to 30 or more set-ups to the mile, each on solar orientation. The result, in effect, for the direction of the established line is the mean of the whole number of solar orientations.

When changing to the normal transit methods for the more refined observations and for the verification of the orientation by the solar unit, note that the reticle of the transit telescope provides a "solar circle"; this is to secure exact coincidence in horizontal and vertical angle readings when making an altitude observation on the sun for azimuth. The solar circle aids materially in making the altitude observaiton, reducing the amount of time in accomplishing coincidence. All readings count to the sun's center, making the data for each observation complete in itself.

Note also, the double cross-wires at left and bottom (direct position of the telescope) spaced at 40" apart, adding to refinement in the sightings, and visibility for the daylight stellar observations. Also, the stadia for both vertical and horizontal rod, helpful on steep vertical angles, both spaced at 1:132 for reductions in the chain unit. The design makes for many additional refinements where increased accuracy is desired, to coordinate with the best use of the solar unit.

Under the conditions and methods as noted, and comparable costs, the survey closures can be held to much smaller limits than can be obtained through any other practice.

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