Young & Sons Improved Solar Compass (Philadelphia, 1881, No. 5474, see Table 4):

This instrument was the later style made with tangent screws to aid in setting and adjusting the latitude and declination arcs. The reproduction of the copper plate image (Fig. 15) in the text shows the original style without such tangent screws. This particular instrument is used regularly to explain the solar compass to the public and pictured here to help demonstrate the various parts described in the text and shown in the image.

Fig. 1

In Fig. 1 the solar compass is set up with the latitude arc, center right, in view. The revolving limb, with its declination arc and (Sun-pointing) limb on which the lenses and image plates are mounted is set for North Declination of the Sun and rotated away from view, is in upper left center. The keystone-shaped compass or needle box is seen at lower center. The two sight vanes are on either end of the under plate with its graduated horizontal circle, seen through one of the two viewing windows just below the compass box. Figs. 2 and 3 show the details of the latitude arc. Fig 3 shows the arc graduated in degree and quarter- degree graduations with

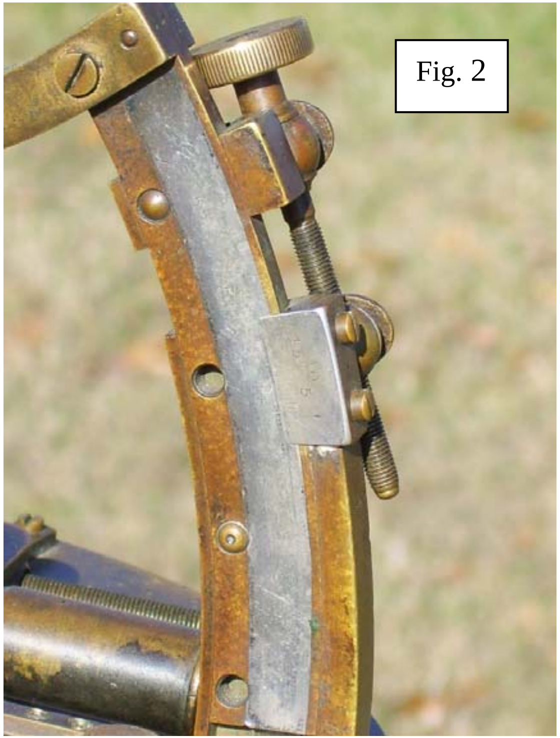

Fig. 2

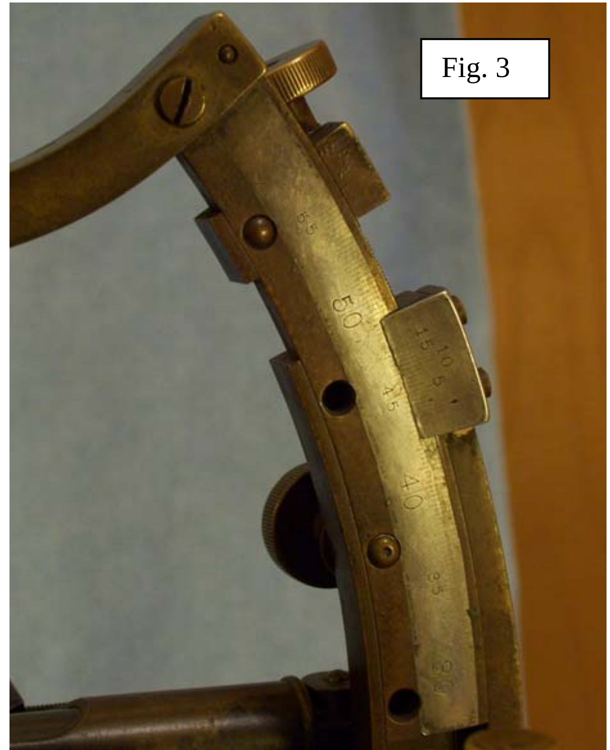

Fig. 3

a 15-division vernier, meaning the least count is 1/4 degree divided by 15, equivalent to 15 minutes of arc divided by 15, = 1 minute of arc.

Fig. 4

Fig. 4 shows the compass rotated 180° with two brass plates with their opposing silver lenses and image plates on the opposite ends of the Sun-pointing limb (at right angles to it) and the declination arc on the upper end at upper center. The original instrument case (wooden) is seen below and behind at the lower right below the right sight vane. Figs. 5 and 6 show the details of the declination arc with its tangent screw. Fig 6 shows the declination arc graduated in degree and quarter-degree graduations with a 15-division vernier, providing a least count of 1 minute of arc, the least count on all the arcs of the solar compass. The declination arc is graduated to 30 degrees, allowing it to also be used with principal stars near the ecliptic, since the Sun does not exceed 23 -1/4 degrees in its north and south declinations. The revolving limb, along with the Sun-pointing limb and declination arc, would be rotated 180° around the polar axis (dark tapered tube in center slanting upper right to lower left) for use during the period of North declinations, as seen in Figs. 6 and 10, being the period from the Vernal to the Autumnal Equinox (mid-March to mid-September), the equinoxes being the two times at which the Sun appears to cross directly over the Equator.

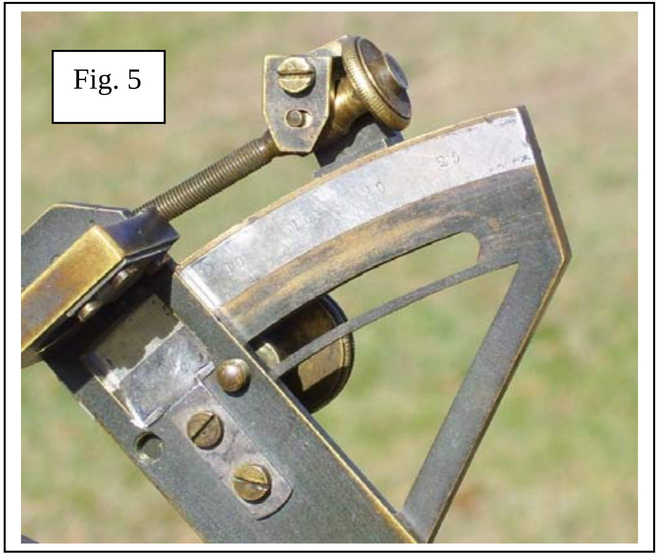
Fig. 5

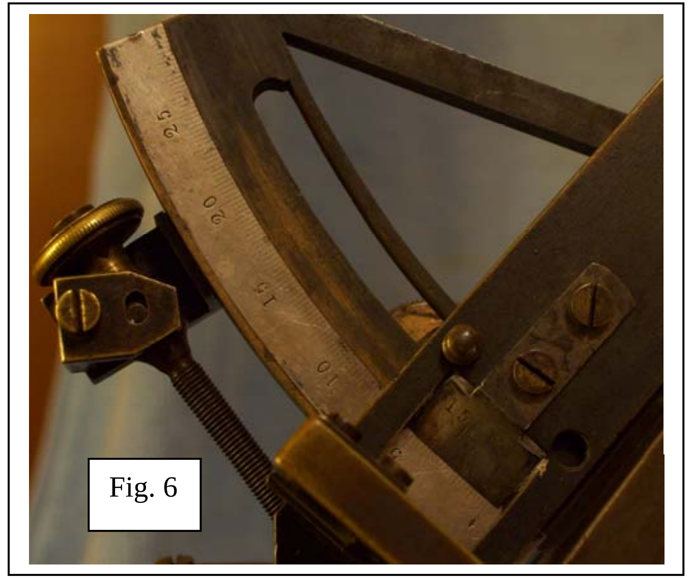
Fig. 6

Fig. 7 pictures the arc on which the last of the three settings needed to operate the Solar Compass was made, that of local apparent time for the meridian at which the instrument was set up. Fig. 8 is a detail of the hour arc showing the graduations in 2-minute increments of time, numbered on the top from 9 AM at right edge to

3 PM at left edge with 12 noon at the center of the arc. The revolving limb is set at noon, with the left (dark) face being the ‘time’ edge through which the axis of rotation of the limb (called the polar axis) is constructed to pass. As can be seen, it is also a quarter of a circle graduated in degrees (0° to 45° from center to left edge and 45° to 90° from right edge to center) and half degrees since 2 minutes of time is equivalent to 30 minutes

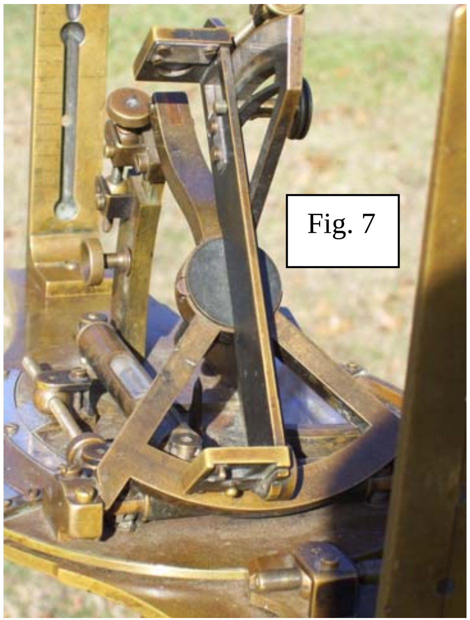

Fig. 7

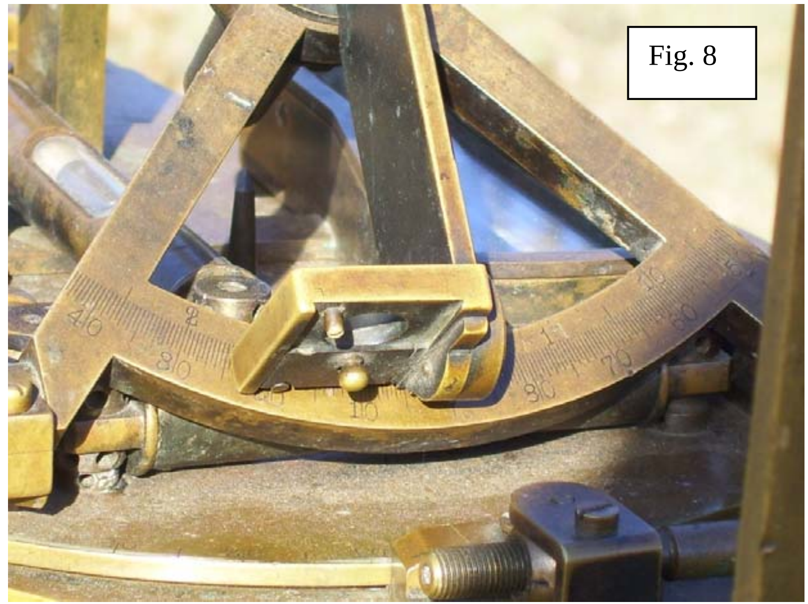

Fig. 8

of arc in terms of longitude. Time was set in hours and minutes of time, not degrees. Thus, to use the Solar Compass one needed to set the latitude which could be obtained at local noon with the instrument set up and leveled and the time set to noon and pointed at the Sun. The declination was available from an ephemeris (time tables for astronomical phenomena events for the Sun and stars), giving the declination for each day at noon at the Greenwich Meridian. Local apparent time could be obtained with the Solar Compass within about two minutes, as noted in the report of the Franklin Institute reviews of the Variation and Solar Compasses. Reasonable values for longitude of many cities were known so the change in time from Greenwich could be determined. Then a daily table for the six hours around local noon was interpolated to set off the declination each hour. The fastest rate of change of declination occurred on the Vernal and Autumnal Equinoxes when it was changing about one minute per hour, the least of change was on the Summer and Winter Solstices when it remains virtually unchanged for the entire day. Once time was determined, the three

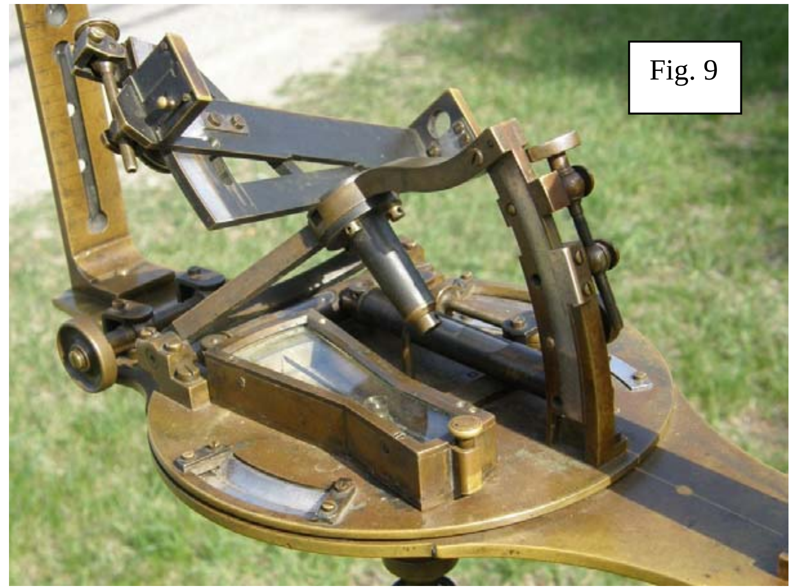

Fig. 9

settings were made on the three arcs and the instrument leveled and rotated horizontally until the Sun's image was seen on the silver image plate at the intersection of the two sets of horizontal (called equatorial) and vertical (called hour) lines. In this orientation the sight vanes were sighting north-south since the solar apparatus was fixed to the upper plate such that it oriented the plate and the noon setting of the hour arc (and the line of sight through the sight vanes) in the local meridian. Since the orientation of the Sun-pointing limb (with the declination arc and its lens and image plates) functions to determine (but not measure) the vertical angle to the Sun at the moment of use, the procedure is a form of that used in making an observation of the Sun for true bearing according to the 'altitude' method. This procedure will give a bearing accurate to within about two minutes of arc if the time is accurate within ten minutes. The Solar Compass provides a mechanical solution (rather than the normal multi-step mathematical computation) to the P-Z-S triangle in astronomical observations with P and Z representing the North Pole and Zenith (the latter being the observer's local latitude on the local meridian also containing the Pole) and S representing the Star, in this case the Sun. This orientation also results in the polar or rotation axis of the hour circle being parallel with the polar axis of the Earth as well as in the plane of the local meridian. Since it is at right angles to the hour circle, the latter is parallel with the plane of the Equator. Thus the solar apparatus can be seen as representing a quarter of a hemisphere of the Earth so that it can, as Burt noted in *A Key to the Solar Compass*, give or lay out the local hour circle of celestial objects near the path of the ecliptic (the path of the Sun in the sky) within about three hours of the local meridian. Retracement surveys of lines established using a Solar Compass show they could achieve accuracies in the range of 2 to 3 minutes of arc when kept in adjustment. Fig. 9 has the revolving and pointing limbs rotated to show lens on far brass plate and a sliding cover over projecting lens on near plate, explained below. In Fig. 10 the Solar Compass is oriented in the local meridian (sight

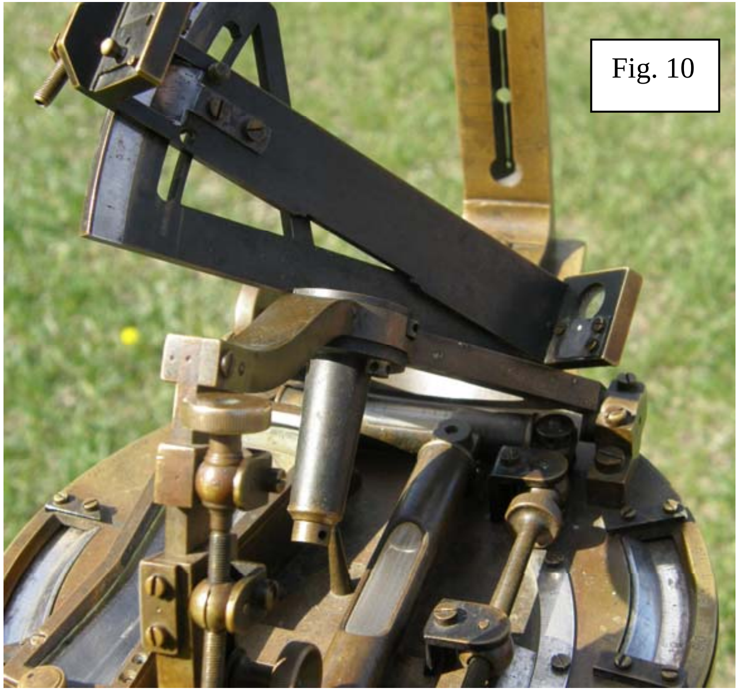
Fig. 10

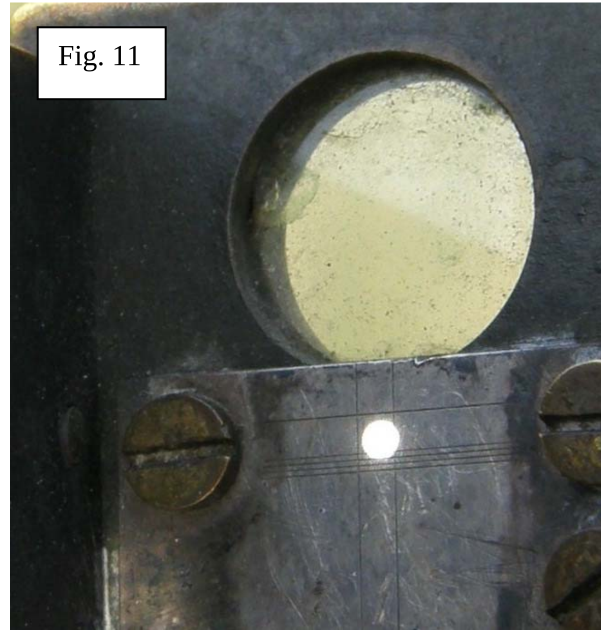
Fig. 11

vane looking North and Sun's image is small light spot on silver plate below lens); the local apparent time is 3 PM. Fig. 11 details the Sun's image on the silver image plate. The lens diameter is about 3/8 of an inch (9.6 mm). The Sun's image is small (slightly less than 1/16 of an inch, or 1.3 mm), but its edges are sharply defined and it fits exactly between the two sets of image lines on the image plate. As the Sun moves so rapidly, it had moved slightly right between the instant that time was set and the picture was taken. There are, of course, two sets of opposing lens and image plates on the two brass plates fastened at right angles to the Sun-pointing limb with its declination arc.. The sliding lens cover, with its small hole (about 1/32 of an inch, or 0.7 mm) seen in Fig. 10 just right of the light colored knob, reduces the Sun's intensity, producing the sharp image in Fig. 11. A full Sun will produce an image with shimmering edges without the use of the cover. Fig. 12 indicates the orientation of the lens and image plate when local apparent time is near noon. The vertical plumb-bob string is in the vertical plane in which the Sun is projected through the lens onto the image plate. The two brass plates are seen as nearly perpendicular to the plumb line. As such, all of the refraction (the downward bending of incoming light rays from stars/Sun) affected declination by increasing it. Fig. 13 shows that at 3PM local apparent time only a percentage of refraction affected declination, as described in the text. Fig. 14 shows the graduations on the sight vanes that allowed the

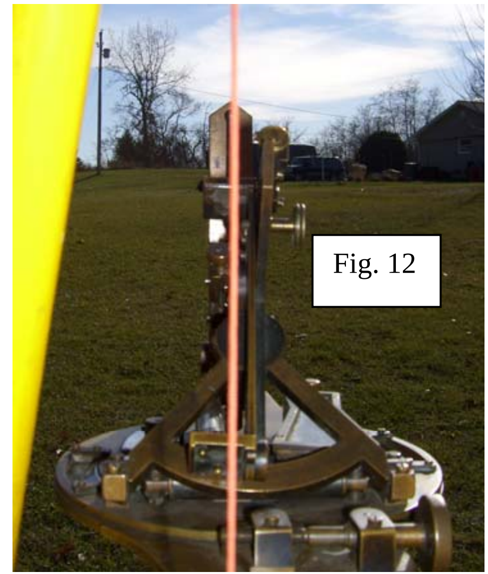

Fig. 12

amount of refraction to be determined by the shadow cast by the vane to the south (on right side: 2, 3, 4 at middle, 5, 7, 9 and 14 minutes at top; left side is degrees for reading vertical angles: 0 to 12 degrees up and down from middle). During periods of North declination it is small (1 to 3 minutes). In Fig. 9 the slotted shadow of the south vane is seen on the both plates with its pointed top on the latitude arc near the top on the tangent screw clamp; it is only about 1 minute at this position. Alternatively, the silver image plates had three lines (Fig. 11) below the paired equatorial image lines (each representing 5 minutes of refraction) allowing the Sun's image position on the plate to be visually adjusted for refraction. Fig. 11 shows the Sun's image as if set for 5 minutes refraction. Burt had Young place 5-degree graduations (and labeled every 10 degrees) on the upper plate so bearings to nearby objects, such as bearing or witness trees,

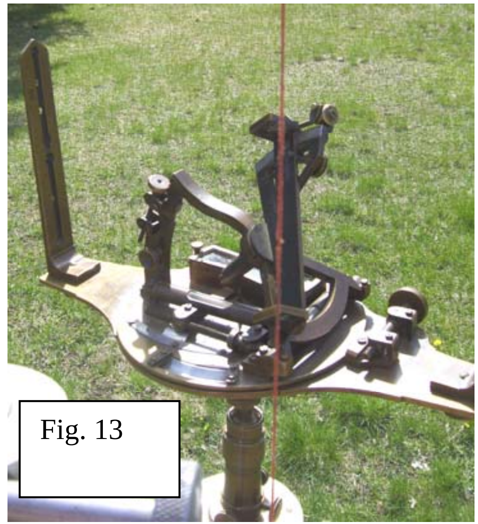
Fig. 13


Fig. 14

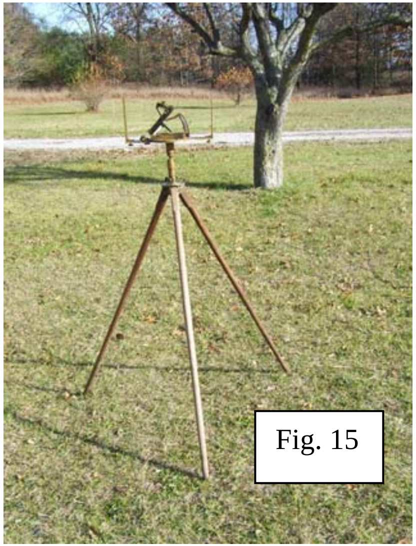
Fig. 15

could be visually determined to the nearest degree for recording in the field notes, by using the center sight pin and eliminating the need to revolve the sight vanes to get the bearing (and thereby saving time). Fig. 15

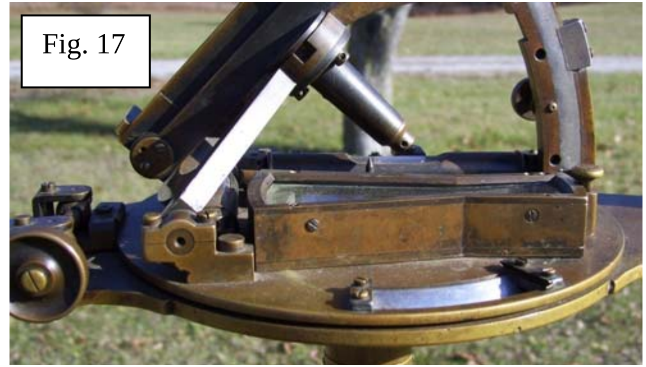
Fig. 17

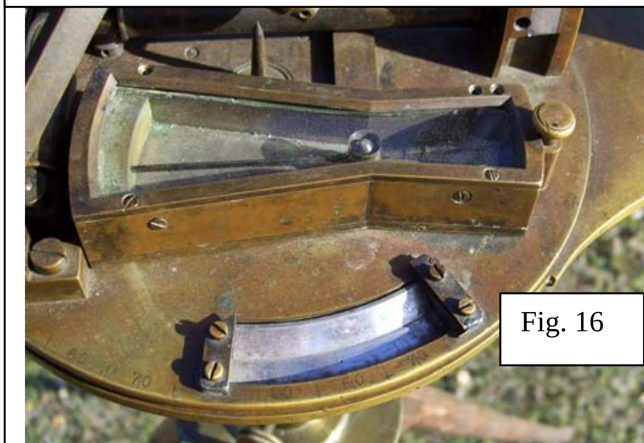
Fig. 16

shows a nearby tree while Fig. 16 shows the graduations on the upper plate and Fig. 17 shows the tree lined up with the sight pin at a bearing of N82°W, the tree opposite at S82°E. The latter bearing would be the bearing recorded in the notes.

Their survey instructions continued to require that Deputy Surveyors record the magnetic declination (changing over time and by location), even after the Solar Compass came into use. A graduated arc (0° to 30° on this Solar Compass, see Fig. 18, upper silver arc) was provided with a tangent screw that rotated the compass box (see Fig. 1) and needle, along with the vernier, up to 30° east and west. Laying off lines of specific direction, defined by a bearing from north or south, was done by sighting through the sight vanes and setting the bearing on the graduated horizontal circle of the under plate (see Fig. 1). Fig. 18 also shows one of the two opposing windows revealing the graduations of the horizontal circle, the lower arc near the edge of the under and upper plates. The upper beveled arc is the vernier (with 30 divisions to right and left) attached to the upper plat, both of which remained fixed while the horizontal circle and under plate could be rotated to lay our or measure a bearing when the fastening or clamp screw (clamp seen in Figs. 4, 7, 8 and 13 and tangent screw; screw is out of view on underside of under plate) was loosened. Burt had Young graduated the horizontal circle just as a ring dial of a surveyors compass: 0° north and south with quarter circles marked off from both increasing to 90° east and west. The horizontal circle could be read to the nearest minute of arc as with all the other arcs.

To lay out due east and west lines, the fastening or clamp screw was loosened and the under plate rotated until the 90° graduations were aligned with the verniers, the exact setting completed with the tangent screw.

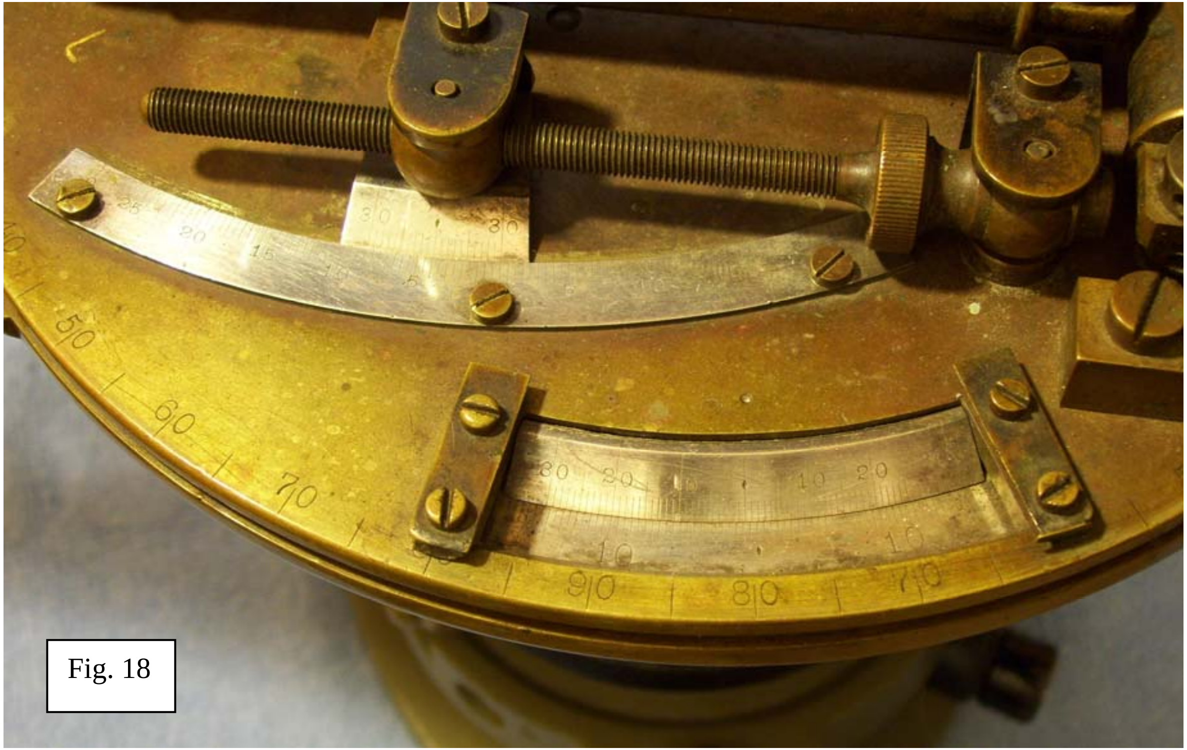

Fig. 18

This, of course rotated the sight vanes as well. However, the upper plate with its solar apparatus and its hour arc remained oriented in the meridian with the 0 hour in the meridian and the pointing limb pointed at the Sun and set to the local apparent time. Fig. 19 shows the Solar Compass in this orientation; the view is looking south, the sight vanes looking east and west. Fig. 20 shows the view looking north. The several views comprising outdoor pictures are taken at two North-South base lines (established by astronomical observation on Polaris with a theodolite) by which to check the adjustments of the Solar Compass.

Fig. 19

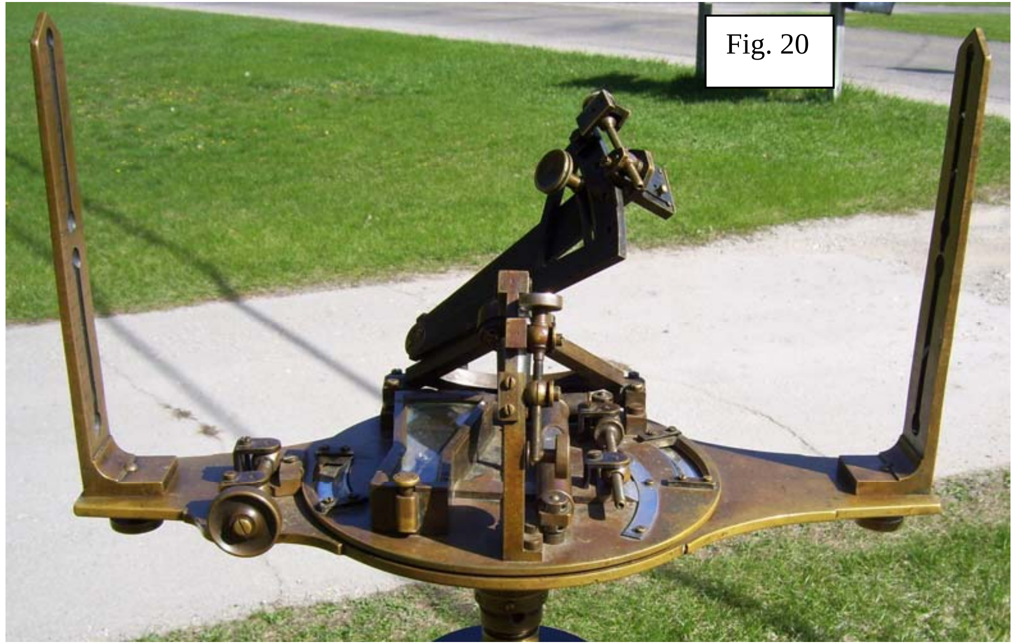

Fig. 20