TECHNICAL REPORT

**THEODOLITE**

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**Introduction**

An instrument used in surveying to measure horizontal and vertical angles with a small telescope that can move in the horizontal and vertical planes. It used to track the movements of either a ceiling balloon or a radiosonde

A theodolite is an instrument for measuring both horizontal and vertical [angles](http://en.wikipedia.org/wiki/Angle), as used in [triangulation networks](http://en.wikipedia.org/wiki/Triangulation). It is a key tool in [surveying](http://en.wikipedia.org/wiki/Surveying) and [engineering](http://en.wikipedia.org/wiki/Engineering) work, particularly on inaccessible ground, but theodolites have been adapted for other specialized purposes in fields like [meteorology](http://en.wikipedia.org/wiki/Meteorology) and [rocket launch technology](http://en.wikipedia.org/wiki/Rocket_launch_technology). A modern theodolite consists of a movable telescope mounted within two perpendicular axes—the horizontal or [trunnion](http://en.wikipedia.org/wiki/Trunnion) axis, and the vertical axis. When the telescope is pointed at a desired object, the angle of each of these axes can be measured with great precision, typically on the scale of [arcseconds](http://en.wikipedia.org/wiki/Arcseconds).

The theodolite is the most accurate and intricate instrument used for horizontal and vertical angles.

It consists of a telescope by means of which distant objects can be sight. The telescope has two distant motions one in horizontal and other is in vertical plane, the former being measured in graduated horizontal circle by means of a set of verniers, and the later on a graduated vertical circle by two verniers. It can also be used for various other purposes such as laying off horizontal angles, locating points on a line, prolonging survey lines, establishing grades, determining differences in elevation, etc.

Theodolites are of various sizes varying from 8cm to 25cm, the diameter of the graduated

circle on the lower plate defining the size.

8 cm to 12cm instruments are used for general survey and engineering works, while 14c to 25cm instruments are used in triangulation work.

**History**

The term *diopter* was sometimes used in old texts as a synonym for theodolite. This derives from an older astronomical instrument called a [dioptra](http://en.wikipedia.org/wiki/Dioptra).

Prior to the theodolite, instruments such as the [geometric square](http://en.wikipedia.org/w/index.php?title=Geometric_square&action=edit&redlink=1) and various graduated circles and semicircles were used to obtain either vertical or horizontal angle measurements. It was only a matter of time before someone put two measuring devices into a single instrument that could measure both angles simultaneously. [Gregorius Reisch](http://en.wikipedia.org/wiki/Gregorius_Reisch) showed such an instrument in the appendix of his book *Margarita Philosophica*, which he published in [Strasburg](http://en.wikipedia.org/wiki/Strasbourg) in 1512. It was described in the appendix by [Martin Waldseemüller](http://en.wikipedia.org/wiki/Martin_Waldseem%C3%BCller), a [Rhineland](http://en.wikipedia.org/wiki/Rhineland) [topographer](http://en.wikipedia.org/wiki/Topographer) and [cartographer](http://en.wikipedia.org/wiki/Cartographer), who made the device in the same year. Waldseemüller called his instrument the *polimetrum*.

The first occurrence of the word "theodolite" is found in the surveying textbook *A geometric practice named Pantometria* (1571) by [Leonard Digges](http://en.wikipedia.org/wiki/Leonard_Digges_(scientist)), which was published posthumously by his son, Thomas Digges. The [etymology](http://en.wikipedia.org/wiki/Etymology) of the word is unknown. The first part of the [New Latin](http://en.wikipedia.org/wiki/New_Latin) *theo-delitus* might stem from the [Greek](http://en.wikipedia.org/wiki/Greek_language) [*θεᾶσθαι*](http://en.wiktionary.org/wiki/%CE%B8%CE%B5%CE%AC%CE%BF%CE%BC%CE%B1%CE%B9), "to behold or look attentively upon" or [*θεῖν*](http://en.wiktionary.org/wiki/%CE%B8%CE%AD%CF%89) "to run" but the second part is more puzzling and is often attributed to an unscholarly variation of one of the following Greek words: [*δῆλος*](http://en.wiktionary.org/wiki/%CE%B4%E1%BF%86%CE%BB%CE%BF%CF%82), meaning "evident" or "clear", or [*δολιχός*](http://en.wiktionary.org/wiki/%CE%B4%CE%BF%CE%BB%CE%B9%CF%87%CF%8C%CF%82) "long", or [*δοῦλος*](http://en.wiktionary.org/wiki/%CE%B4%CE%BF%E1%BF%A6%CE%BB%CE%BF%CF%82) "slave", or an unattested Neolatin compound combining [*ὁδός*](http://en.wiktionary.org/wiki/%E1%BD%81%CE%B4%CF%8C%CF%82) "way" and [*λιτός*](http://en.wiktionary.org/wiki/%CE%BB%CE%B9%CF%84%CF%8C%CF%82) "plain". It has been also suggested that *-delitus* is a variation of the Latin [supine](http://en.wikipedia.org/wiki/Supine) [*deletus*](http://en.wiktionary.org/wiki/deletus), in the sense of "crossed out".

There is some confusion about the instrument to which the name was originally applied. Some identify the early theodolite as an [azimuth](http://en.wikipedia.org/wiki/Azimuth) instrument only, while others specify it as an [altazimuth](http://en.wikipedia.org/wiki/Altazimuth) instrument. In Digges's book, the name "theodolite" described an instrument for measuring horizontal angles only. He also described an instrument that measured both altitude and azimuth, which he called a *topographicall instrument*. Thus the name originally applied only to the azimuth instrument and only later became associated with the altazimuth instrument. The 1728 [*Cyclopaedia*](http://en.wikipedia.org/wiki/Cyclopaedia) compares "[graphometer](http://en.wikipedia.org/wiki/Graphometer)" to "half-theodolite". Even as late as the 19th century, the instrument for measuring horizontal angles only was called a *simple theodolite* and the altazimuth instrument, the *plain theodolite*.

The first instrument more like a true theodolite was likely the one built by [Joshua Habermel](http://en.wikipedia.org/w/index.php?title=Joshua_Habermel&action=edit&redlink=1) ([de:Erasmus Habermehl](http://de.wikipedia.org/wiki/Erasmus_Habermehl)) in Germany in 1576, complete with compass and tripod.

The earliest altazimuth instruments consisted of a base graduated with a full circle at the [limb](http://en.wiktionary.org/wiki/Limb#Etymology_2) and a vertical angle measuring device, most often a semicircle. An [alidade](http://en.wikipedia.org/wiki/Alidade) on the base was used to sight an object for horizontal angle measurement, and a second alidade was mounted on the vertical semicircle. Later instruments had a single alidade on the vertical semicircle and the entire semicircle was mounted so as to be used to indicate horizontal angles directly. Eventually, the simple, open-sight alidade was replaced with a sighting [telescope](http://en.wikipedia.org/wiki/Telescope). This was first done by [Jonathan Sisson](http://en.wikipedia.org/w/index.php?title=Jonathan_Sisson&action=edit&redlink=1) in 1725.

The theodolite became a modern, accurate instrument in 1787 with the introduction of [Jesse Ramsden](http://en.wikipedia.org/wiki/Jesse_Ramsden)'s famous great theodolite, which he created using a very accurate [dividing engine](http://en.wikipedia.org/wiki/Dividing_engine) of his own design. As technology progressed, in the 1840s, the vertical partial circle was replaced with a full circle, and both vertical and horizontal circles were finely graduated. This was the *transit theodolite*.

Theodolites were later adapted to a wider variety of mountings and uses. In the 1870s, an interesting waterborne version of the theodolite (using a pendulum device to counteract wave movement) was invented by [Edward Samuel Ritchie](http://en.wikipedia.org/wiki/Edward_Samuel_Ritchie). It was used by the U.S. Navy to take the first precision surveys of American harbors on the Atlantic and Gulf coasts. With continuing refinements, the instrument steadily evolved into the modern theodolite used by surveyors today.

**Classifications**

Theodolites are classified as (i) transit, (ii) non- transit:

There are three main types, (i) the transit, (ii) the plane or Y and (iii) the Everest. A theodolite is called a transit, when its telescope can be revolved through a complete revolution about its horizontal axis in a vertical plane.

The first type is transiting and the other two are non-transiting. The transit type is largely used, while the other two types have now become obsolete.

Theodolites are also classed as:

1. Vernier Theodolites
2. Optical Reading Theodolite
3. Digital Theodolite/Electronic Theodolite
4. There Are Various Kinds Of Theodolites:
5. Repeating Theodolite
6. Direction Theodolites

**Components of Transit theodolite –**  
 Transit theodolite consists of the following parts:   
1. Levelling Head  
2. Lower Plate or Scale Plate  
3. Upper Plate or Vernier Plate  
4. The standard or A Frame  
5. T-Frame or Index Bar.  
6. Plate Levels  
7. Telescope

**Levelling Head**: Levelling Head consists of upper tribrach and lower Tribrach. Upper tribrach has three arms; each arm carries a levelling screw for levelling the equipment. Lower tribrach has got a circular hole through which a plumb bob may be suspended for centering.  
Three distinct functions of levelling head are:  
 i) to support the main part of the instrument  
ii) to attach the Theodolite to the Tripod  
iii) to provide a means for levelling the theodolite

**Lower Plate (Scale Plate)**: Lower Plate which is attached to outer spindle, carries a horizontal graduated circle, it is graduated from 0-360. Each degree is further divided into 10 minutes or 20 minutes. Scale plate can be clamped to any position by a clamping screw and a corresponding slow motion screw.  
When the lower plate is tightened, the lower plate is fixed to the upper tribrach of the levelling head. The size of the Theodolite is determined by the size of the diameter of this lower plate.

**Upper plate or Vernier Plate:** Upper plate is attached to Inner spindle axis. Two verniers are screwed to the upper plats. It carries an upper clamp screw and tangent screw. On clamping the upper clamp and unclamping the lower clamp, the instrument may be rotated on its outer spindle without any relative motion between the two plates.  
  
 On the other hand if lower clamp screw is tightened and upper clamp screw is unclamped, the instrument may be rotated about its inner spindle with a relative motion between the vernier and graduated scale of the lower plate. This property is utilized for measuring angles.

**The standard or A Frame:** Two uprights called standards or A frame sand upon the vernier plate to support the horizontal axis.

**T-Frame or Index Bar:** The index bar is T-shaped and centered on the horizontal axis of the telescope in the front of vertical circle. It carries two verniers at the extremities of its horizontal arms or limbs called the index arm. The vertical leg called the clipping arm is provided with a fork and two screws called the clip or clipping screws at its lower extremity. By means of these screws, it is secured to a piece of metal projection from the cross bar of either A support. The index arm and the clipping arm are together known as the T frame. A long sensitive bubble tube called the altitude or azimuthal bubble tube is attached to the top of the frame. It can be centered by means of clip screws. In some instruments it is set on the top of the telescope.

**Plate Levels**: Upper plates carries two plate levels placed at right angles to each other. One of the plate bubble is kept parallel to the trunion axis. Plate levels can be centered with the help of foot screws.

**Telescope:** Telescope is supported on the pivots of the trunion axis which affords its movement in the vertical plane.

**Adjustment**

* Find a patch of firm level ground with a good view of what you wish to spot.
* Extend the legs of the tripod so that the theodolite will be at a comfortable level for you to use, splay them as far as they will go (most theodolite tripods will have a mechanism that will lock them when they reach their maximum separation and extension), and stick the ends of the legs into the earth as much as you can.
* Adjust the three leveling screws on the base of the theodolite so that it is level. The spherical spirit level mounted on the theodolite will give you an idea of when it is roughly level.
* Align the long spirit level with two of the three screws and readjust with those two screws to achieve a more accurate level on that axis. Then turn the theodolite 90 degrees on its base and adjust again using the third screw.
* Release the two horizontal adjuster clamps (usually large knobs on either side of the theodolite, slightly vertically offset).
* Align the upper part of the theodolite with the mark on the ring between the two sides which are connected to the horizontal clamps, then lock the upper clamp.
* Open the mirror light source on the side of the theodolite, and look through the small eyepiece. You will see three scales: horizontal, vertical, and fine adjustment. Use the fine adjustment knob on the upper part of the theodolite to align the mark with 0'00" (0 minutes and 0 seconds of arc).
* Use the upper horizontal adjustment knob to align the single line you see in the scope on the bottom half of the horizontal scale exactly between the double lines which sit below the number 0.
* Create a reference line by lining up the theodolite horizontally with a tall landmark within easy view. Unlock the lower clamp to make this rotation, line the sight up with the landmark, and lock the lower clamp again. The horizontal measurement will still be zero. From now on, only loosen the upper clamp to make horizontal adjustments.

**Taking A Measurement**

**Horizontal Angle Measuring**

Unlock the upper horizontal clamp, and rotate the theodolite until the arrow in the rough sights is lined up with the point you wish to measure, then lock the clamp. Use the upper horizontal adjuster (not the clamp) to align the object between the two vertical lights in the sight.

Look through the small eyepiece, and using the fine adjustment knob to get a precise horizontal line up with your object. The degrees from your reference are measured on the horizontal degree scale, the minutes and seconds on the fine adjustment scale (ex. 30 degrees 10'30").

**Vertical Angle Measuring**

Unlock the vertical clamp and look through the sight while moving the theodolite up and down to find the precise spot vertically on your object that you'd like to measure. Lock the clamp and use the fine vertical adjustment knob to get a precise fix on the point you've chosen. Then look through the small eyepiece and read off the degrees, minutes and seconds from the vertical scale and the fine adjustment scale as you did for the horizontal scale. If your object is up high you'll need to do a rough horizontal adjustment first, then do the vertical measurement, then readjust for the final horizontal measurement. These two coordinates give the exact angle between your reference and your point of interest, but you can also measure the angle between two points by comparing their two measurements, or by setting the first point as the reference.

**Types of Errors**

The sources of error in the theodolite observation may be classified as

1. Instrumental error
2. Personal error
3. Natural error

**Instrumental Error.**

The instrumental errors are due to (i) imperfect adjustment of the instrument, and (ii) structural defects in the instrument.

1. **Error due to non- adjustment of plate levels:** when plates bubbles, which are not perpendicular to the vertical axis are centered, the vertical axis of the instrument will not be truly vertical, and error will be introduced in the measurements of both horizontal and vertical angles. As a result, the horizontal circle is inclined. Hence angles are measured in an inclined plane and not in a horizontal plane. The error is serious when horizontal angles between the points at considerably different elevations are to be measured. The error may be minimized by levelling the instrument carefully with references to the altitude bubble or the telescope bubble.
2. **Error due to the line of collimation not bring perpendicular in the horizontal axis**: if the line of collimation is not perpendicular to the horizontal axis, it will not revolve in plane, but will trace out the surface of a cone instead of a plane when the telescope is revolved on th horizontal axis i.e. raised or lowerd. The trace of the intersection of the conical surface with the vertical plane containing the point sighted will be hyperbolic. As a result of this error, horizontal angles, when measured between points at widely different elevation will be in error.
3. **Error due to the line of collimation not brings perpendicular in the vertical axis:** if the horizontal axis is not perpendicular to the vertical axis, the line of collimation will not revolve in vertical plan as the telescope is raised or lowered.

The resulting angular error affects both horizontal and vertical angles and depends upon (1) the inclination of the horizontal axis to the perpendicular to the vertical axis, and (2) the vertical angle to the point sighted. The error is considerable when points between which horizontal angles are to be measured are at very different elevations. The magnitude of the error may be obtained thus.

**Personal Error**

1. **Errors of manipulation:**
2. This error includes
3. Inaccurate centering
4. Inaccurate levelling
5. Slip
6. Manipulation of wrong tangent screw
7. **Errors in sighting and reading:**
8. Inaccurate bisection of the point observed
9. Non vertically of ranging rod
10. Displacement of ranging rod or peg
11. Parallax.

**Natural Error**

1. Unequal atmospheric refraction due to high temperature.
2. Unequal expansion of parts of telescope and circles due to temperature changes.
3. Unequal settlement of tripods.
4. Wind producing vibrations.
5. High temperature producing irregular refractions
6. The sun shining on the instrument

**PRECAUTIONS**

* **Instrument check.** Check the instruments and targets for stability. If an instrument is not stable, all other refinements are useless.
* **Instrument adjustment.** Pay careful attention to the parallax and the inclination of the horizontal circle plate. Errors introduced by the parallax and the inclination cannot be eliminated.
* **Signal and target centering.** Plumb signals and targets directly over the SCP. Carefully aim signals and targets towards the observing station.

Other operational precautions for accurate observations are as follows:

* Repoint on the initial target after each circle setting.
* Check the plate level frequently.
* Protect the instrument from wind, sunshine, and precipitation.

**References**

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