CHAPTER 05

Theodolites

5.1 Theodolite

Theodolite is an instrument used for measuring the horizontal and vertical angles in survey works. It is a very important instrument in surveying and can be used in a large number of survey works like measurement of distances, levelling, prolonging a line etc.

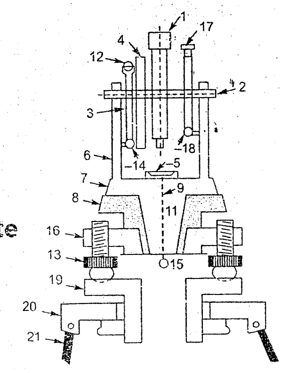
5.1.1 Transit Theodolites

- Earlier the theodolites were manufactured with long telescopes which could not be rotated through 180° about the horizontal axis i.e. in the vertical plane.
- Later on theodolites with shorter telescope were developed which could be rotated through 180° in the vertical plane about the horizontal axis. These theodolites are called as **transit theodolites** since in them; the line of sight can be rotated about the horizontal axis.
- Now a days, all the theodolites are manufactured with small telescope and thus the words theodolite and transit theodolite are used synonymously.

Theodolites are of two types. viz.:

(a) **Vernier theodolite** : In case of Vernier theodolites, verniers are used for taking the readings and are used most commonly for general works. The least count of Vernier theodolite is **20 seconds (20″)**.

(b) **Optical theodolite** : Optical theodolites are provided with optical systems for reading both the horizontal and the vertical angles. In fact these theodolites are fitted with a micro meter and are also called as **micro meter theodolites.** The least count of these theodolites is **1 second (1″)**.



1 Telescope
2 Trunnion axis
3 Vernier frame
4 Vertical circle
5 Plate levlel
6 Standard
7 Upper plate
8 Lower plate
9 Inner axis
10 Outer spindle
11 Inner spindle
12 Altitude bubble
13 Levelling screw
14 Clip screw
15 Hook
16 Tribrach
17 Vertical Clamp screw
18 Vertical Tangent screw
19 Trivet
20 Tripod
21 Tripod leg

Fig. 5.1 Vernier theodolite

5.2 Components of a Vernier Theodolite

(a) **Telescope:** The telescope is mounted on a horizontal spindle called as trunnion axis. The telescope can be rotated through 180° in the vertical plane. This telescope is internal focusing type with aperture of objective as 38 mm.

The length of the telescope tube varies from 100 mm to 175 mm. The shortest focusing distance is about 3 m and field of view is about 1° 30′. The trunnion axis is supported at the two ends in the bearings carried in standard frame called as *A* **frame.** The standards are fixed on the upper plate. Focusing screw is provided at one end of the trunnion.

(b) **Vertical circle:** The vertical circle is secured tightly to the telescope and moves when the telescope is rotated about the horizontal axis.

The vertical circle is graduated with graduations marked from 0° to 90° in opposite directions. The two zeros of the vertical circle are on the horizontal diameter of the circle.

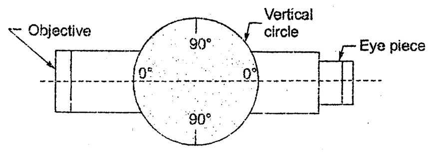


Fig. 5.2 *Vertical circle of vernier theodolite*

The vertical angles are measured by a pair of verniers (called as Vernier *C* and *D*) fixed diametrically opposite to each other. Verniers are fixed on a frame called as *T* **frame.** The least count of the Vernier is 20″.

(c) **Vernier frame:** The Vernier frame is also called as *T* frame or the index frame. The vertical leg of this *T* frame is called as clipping arm and the horizontal arm is called as index arm. On the two ends of the index arm are fixed the verniers *C* and *D*. The clipping arm (or the vertical leg of *T* frame) is provided with a clipping screw at its lower end. **(Fig. 5.3)**

The verniers *C* and *D* are stationary while the main vertical circle moves with the telescope. Glass magnifiers are also provided in front of each Vernier to magnify the Vernier readings.

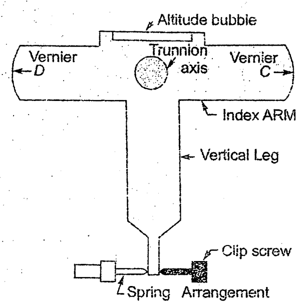


Fig. 5.3 Vernier frame of theodolite

(d) **Vertical clamp screw:** The vertical circle and hence the telescope can be clamped at any vertical angle by the vertical clamp screw. This prevents the rotation of the telescope about the horizontal axis in the vertical plane. But after clamping the vertical screw, small rotations of the telescope in the vertical plane can be made by means of vertical tangent screw.

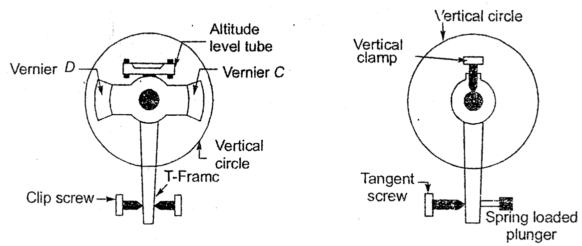


Fig. 5.4 *Vertical clamp screws*

(e) **Altitude bubble:** This is the sensitive level tube attached at the top of *T* frame. The sensitivity of altitude bubble tube is 20″ per 2 mm.

(f) **Upper plate:** The upper plate also called as Vernier plate supports the standard at its upper surface. At its lower surface, the upper plate is attached to the vertical spindle called as the inner spindle or the inner axis. The inner spindle rotates in the outer spindle attached to the lower plate when the upper plate is unclamped. The upper plate can be clamped to the lower plate by the upper clamp screw. The upper tangent screw is used for making small movement of the upper plate after tightening the upper clamp screw. After clamping the upper plate, both upper and lower plates move together as one unit.

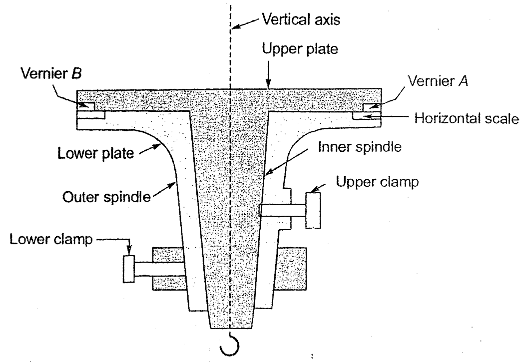


Fig. 5.5 *Upper plate of vernier theodolite*

(g) **Lower plate:** The lower plate is also called as the horizontal circle or the main scale plate. It is mounted on a hollow tapered spindle also referred to as the outer spindle or the outer center. It is to be noted that the inner surface of the outer spindle acts as bearing for the inner spindle. The outer surface of the outer spindle turns in the bearing in the tribrach of the levelling head.

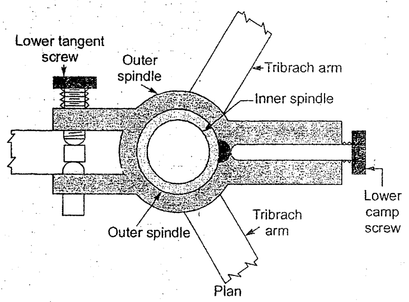


Fig. 5.6 Lower plate of vernier theodolite

The lower plate is graduated from 0° to 360° with each graduation at 20′. Each fifth degree is numbered and the graduations increase in the clockwise direction. The edge of the horizontal circle is beveled and silvered.

The readings of the horizontal circle are taken by verniers *A* and *B*.

The lower plate is provided with lower clamp screw. When the lower clamp is tightened, then the outer spindle is fixed to the tribrach and the lower plate gets fixed in position. Similar to upper plate, when the lower clamp screw is tightened, the lower plate can be rotated slightly by turning the lower tangent screw.

The diameter of the horizontal circle is between 100 mm to 130 mm.

(h) **Plate level:** A level tube called as the plate level is provided on the upper plate of the theodolite. The sensitivity of this plate level is about 35″ per 2 mm. In certain instruments, there are two level tubes fixed horizontally at right angles to each other.

(i) **Levelling head:** The levelling head consists of two plates which are parallel to each other separated by three levelling screws. The upper parallel plate of the levelling head is called as the **tribrach** and the lower parallel plate is called as the **trivet stage** or **foot plate.** The tribrach supports the outer spindle with the help of tapered bearings. The tribrach consists of three arms each carrying a levelling screw.

(j) **Shifting head:** It is a centering device placed below the lower plate but above the tribrach so as to enable the centering after the instrument has been levelled. It consists of two plates capable of moving relative to each other.

(k) **Magnetic compass:** A circular type of magnetic compass is generally used. It is mounted on the upper plate between the standards. When the telescope is in the normal position (face left), the letter *N* of the compass is under the objective end of the telescope and letter *S* is under the eye piece end. The magnetic compass indicates zero when the line of sight points towards the north. The magnetic bearing increases as the telescope is turned clockwise. The working of this magnetic compass is very similar to that of Surveyor's compass.

(l) **Tripod:** The theodolite is mounted on a tripod when used in the field. The legs of the tripod are either solid or framed. Pointed steel shoes are provided at the lower ends of the tripod legs so that the tripod legs can be pushed inside the ground for fixing purposes.

5.2.1 Terminologies in Theodolite Surveying

For making measurements with theodolite in field, a number of operations are required.

Theodolite has a number of axes which bear a definite relation with each other.

(a) **Transit:** It the operation of revolving the telescope through 180° in a vertical plane about the horizontal axis. This operation is also called as **plunging** or **reversing.**

(b) **Face Right:** When vertical circle of the theodolite is on the right of the observer, then the theodolite is said to be in face right condition and the corresponding measurements are called as **face right measurements.**

(c) **Face Left:** When vertical circle of the theodolite is on the left of the observer, then the theodolite is said to be in face left condition and the corresponding measurements are called as **face left measurements.**

By taking mean of measurements of both the face readings, the collimation error is eliminated.

(d) **Changing Face:** It the operation of bringing the telescope from face left condition to face right condition and vice versa.

(e) **Double Sighting:** It is the process of making the horizontal and vertical measurements twice viz. one with telescope in normal (face left) condition and other with telescope in inverted (face right) condition.

(f) **Swing the telescope:** It is the operation of revolving the telescope in the horizontal plane about the vertical axis. Clockwise rotation is called as **right swinging** and anticlockwise rotation is called as **left swinging.**

By taking mean of observations of both the swinging, the error due to friction or backlash in the moving parts can be eliminated.

(g) **Telescope normal:** The telescope is said to be in normal position when vertical circle is on the left of the observer.

(h) **Telescope inverted:** The telescope is said to be in inverted position when vertical circle is on the right of the observer.

(i) **Centering:** It is the operation of setting up the instrument exactly over the station mark. A plumb bob suspended from the underside hook of the instrument is used for centering purpose.

(j) **Vertical axis:** The vertical axis of the theodolite is the axis about which instrument rotates in the horizontal plane and this axis is also called as **azimuth axis.** The telescope and the horizontal circle can rotate about the vertical axis independent of each other.

(k) **Horizontal axis:** It is the axis about which a telescope rotates in the vertical plane. It is also called as **trunnion axis** or the **transverse axis.**

(l) **Axis of the plate level:** It is the straight line which is tangential to the longitudinal curve of the plate level tube at its center. When the bubble is centered then the axis of the plate level is horizontal.

(m) **Line of collimation:** It is the (imaginary) line passing through the intersection of cross hairs on the diaphragm and the optical center of the objective.

5.3 Measurement of Horizontal Angles

5.3.1 Measurement of Deflection Angles

- A deflection angle is the angle which the line makes with the prolongation of the preceding line.
- This deflection angle is designated as right (*R*) when the deflection angle is measured clockwise and is designated as left (*L*) when the deflection angle is measured anticlockwise.
- The value of deflection angle can vary from 0° to 180°.

The following steps may be adopted to determine the right deflection angle 'δ' at point *Q* as shown in Fig. 5.7.

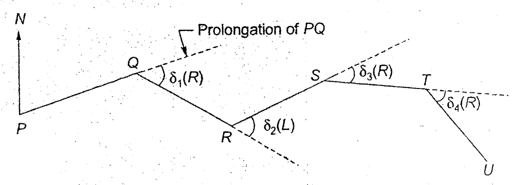


Fig. 5.7 *Measurement of Deflection Angle*

Step 1. Set up the Vernier theodolite at station *Q* and center it and level it. Keep the orientation of the vertical scale as face left. Set the Vernier *A* to zero and clamp the upper plate.

Step 2. Take back sight at station preceding station *P* and clamp the lower plate. Bisect *P* using the lower tangent screw.

Step 3. Plunge the telescope so the line of sight is now along the prolongation of the line *PQ* with reading on the Vernier still equal to zero.

Step 4. Unclamp the upper plate and turn the telescope clockwise to sight at station *R*. Bisect *R* using the upper tangent screw. Read both the verniers *A* and *B*. The mean of the two Vernier readings is the deflection angle, δ.

Step 5. Unclamp the lower plate and turn the telescope to sight at station *P* again. Telescope is in inverted position at this stage.

Step 6. Plunge the telescope so that the telescope is now in the normal position.

Step 7. Unclamp the upper plate and again sight at station *R* by turning the telescope clockwise. Clamp the upper plate and bisect *R* using the upper tangent screw. Read both the verniers *A* and *B*.

In the above process, the deflection angle is doubled and thus one half of the total value is the deflection angle.

NOTE: For left deflection angles, Vernier A gives the value of (360° − δ).

5.3.2 Measurement of Magnetic Bearings

- Theodolite when provided with compass can be used for the measurement of magnetic bearings of lines. The following procedure is adopted:

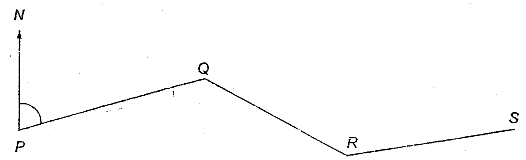


Fig. 5.8 *Measurement of Magnetic Bearing*

Step 1. Set up the instrument at station *P* and center it and level it. Keep the orientation of vertical scale to face left. Clamp the upper plate.

Step 2. Unclamp the lower screw and release the magnetic needle. Turn the telescope until the magnetic needle takes it normal position.

Step 3. Clamp/tighten the lower clamp. Using the lower tangent screw, bring the needle so that the needle marks exactly against the zero mark. At this point, Vernier *A* reads the value as zero and the instrument gets oriented.

Step 4. Unclamp the upper plate and turn the telescope towards the station *Q*. Tighten the upper plate and bisect station *Q* using the upper tangent screw.

Step 5. Read both the verniers and mean of both the readings is equal to magnetic bearing of line *PQ*.

Step 6. Now change the face of vertical scale to face right. Loosen the upper plate and set the Vernier *A* to zero and then tighten the upper clamp. Repeat steps (2) to (5) again and again to determine bearing of line *PQ*.

Step 7. Take mean of the values obtained in step (5) and (6) above which ultimately gives the magnetic bearing of line *PQ*.

NOTE: For determining the true bearing of a line then astronomical observations are required to be made.

5.4 Theodolite as a Level

- A perfectly adjusted theodolite can be used as a levelling instrument as well.
- When bubble of the altitude level is at the center of the tube and Vernier reading is zero, then the line of sight is horizontal and theodolite can be used as a levelling instrument.
- Just like in levelling principle, the *R.L.* of the point of unknown elevation can be determined as:

$$R.L. = \text{Bench Mark} + \text{Back Sight} - \text{Fore Sight}$$

- The accuracy attained by the theodolite as a levelling instrument is less than that of dumpy level or a tilting level.

5.5 Angular Measurement Methods

(a) Loose needle method of bearings
(b) Fast needle method of bearings
(c) Method of included angles
(d) Method of direct angles
(e) Method of deflection angles

5.5.1 Loose Needle Method

- In this method, the direction of the magnetic meridian is established at each of the traverse station and direction of the line is determined with respect to the magnetic meridian; i.e. magnetic bearing of each line is determined.
- When theodolite is provided with a magnetic compass, then this theodolite can be used for determining the magnetic bearings of different traverse lines. This procedure is very similar to the compass traverse.
- The least count of Vernier theodolite is 20″ but compass can read up to an accuracy of 5′. Now the magnetic bearing of the traverse lines are read from the compass, and thus the accuracy of the loose needle method is that of compass and not that of theodolite.
- Loose needle method is often not used in theodolite traverse.

5.5.2 Fast Needle Method

- In this method, the magnetic meridian is established only at one traverse station. The magnetic bearing of first line is measured directly.
- The magnetic bearings of all other traverse lines are determined from the magnetic bearing of first line and the included angles.
- Though the magnetic bearing of the first line has an accuracy of the compass, the difference of bearings of two adjacent lines has an accuracy of a theodolite.
- This method is called fast needle method because the verniers remain clamped with respect to initial setting of the magnetic meridian.
- This method is more accurate than the loose needle method.

The fast needle method of traversing can be done by the following methods:

1. **Direct method with transiting:** This method is easy to use but is not accurate case instrument is not in adjustment.
2. **Direct method without transiting:** It is the best method as for as accuracy is concerned and can even be used when the instrument is not in perfect adjustment.
3. **Back bearing method:** It is not an easy method since at each station, backsighting has to be done along with orientation. Thus it is rarely used in practice.

5.5.3 Method of including Angles

- In this method, magnetic bearing of any one line is measured in field.
- All the included angles are measured.
- Thus bearing of all other lines are determined from the bearing of initial line and the included angles.
- It is more accurate than fast needle method.

5.5.4 Method of Direct Angles

- This method is very similar to method of included angles but here direct angles or the angles to the right are measured. This method is suitable for open traverse.

5.5.5 Method of Deflection Angles

- This is mainly used for open traverse for survey of roads, railway lines, canals, sewers, pipe lines etc. Here the traverse lines make small deflection angles.

5.6 Mistakes in Theodolite Surveying

(a) **Error in reading the vernier:** It is quite usual that the observer may take a wrong reading from the Vernier. A good practical judgment of the value of fractional part of the angle from the main scale reading can reduce the errors due to wrong readings taken from Vernier.

(b) **Reading the wrong Vernier:** In situations where double verniers are provided for the horizontal scale, it is quite usual to take reading from the wrong Vernier if proper attention is not paid. Similarly in the vertical Vernier, the Vernier may be read in the wrong direction.

(c) **Reading the wrong horizontal scale:** In situations where horizontal scale is marked in both clockwise and anticlockwise directions, it may be possible that the observer may take reading from the wrong scale. Thus it is always recommended to check the adjacent numbers on the scale.

(d) **Turning of wrong tangent screws:** In Vernier theodolites, when the angle is measured by the method of repetition, the turning of wrong tangent screws (upper tangent screw in place of lower tangent screw and vice-versa) leads to mistakes in the reading.

(e) **Wrong setting and sighting:** This type of error occurs during the wrong setting of instrument or sighting the wrong signal.

(f) **Entering the wrong values:** Wrong entry of observations in the record book leads to errors in further computations.

(g) **Omission of signs with angles:** Omission of plus or minus sign with angles while noting down the reading may lead to errors in computations.

(h) **Omission of necessary word during recording:** In case of deflection angles, the words **left** or **right** need to be specified along with the deflection angle. Without these, the complete description of deflection angle is not justified.

Objective Brain Teasers

Q.1 The process of revolving the telescope about its vertical axis in the horizontal plane is
(a) Transiting (b) Swinging
(c) Transmitting (d) Face left

Q.2 The process of revolving the telescope about its horizontal axis in the vertical plane is
(a) Transiting (b) Traversing
(c) Face right (d) None of these

Q.3 Which of the following defines the size of theodolite?
(a) Diameter of graduated circle of upper plate
(b) Diameter of graduated circle of lower plate
(c) Length of telescope
(d) None of these

Q.4 Which of the following fast needle method is most preferred?
(a) Direct method with transiting
(b) Back bearing method
(c) Direct method without transiting
(d) None of these

Q.5 For determining the relative positions of a large number of points, the most preferred method is
(a) Theodolite traverse
(b) Chain traverse
(c) Compass traverse
(d) Triangulation

Q.6 In theodolites, parallax can be removed by
(a) refocusing the eyepiece and objective
(b) refocusing only the eyepiece
(c) refocusing only the objective
(d) None of these

Q.7 In loose needle method, the accuracy of magnetic bearing is that of
(a) Vernier theodolite
(b) Compass
(c) Micrometer
(d) None of these

Q.8 In fast needle method, the accuracy of difference of bearings is that of
(a) Vernier theodolite
(b) Compass
(c) Vertical circle
(d) None of these

Q.9 Which of the following is true as far as accuracy is concerned?
(a) Method of included angles > Fast needle method > Loose needle method
(b) Fast needle method > Method of included angles > Loose needle method
(c) Fast needle method > Loose needle method > Method of included angles
(d) Loose needle method > Method of included angles > Fast needle method

Q.10 Which of the following is suitable for laying of sewer lines?
(a) Fast needle method
(b) Method of included angles
(c) Method of direct angles
(d) Method of deflection angles

Answers

1.	(b)	2. (a)	3. (b)	4. (c)	5. (a)
6.	(a)	7. (b)	8. (a)	9. (a)	10. (d)