6

The Theodolite

6.1. GENERAL

The Theodolite is the most precise instrument designed for the measurement of horizontal and vertical angles and has wide applicability in surveying such as laying off horizontal angles, locating points on line, prolonging survey lines, establishing grades, determining difference in elevation, setting out curves etc.

Theodolites may be classified as :

(*i*) Transit theodolite.

(*ii*) Non-transit theodolite.

A *transit theodolite* (or simply '*transit*') is one is which the line of sight can be reversed by revolving the telescope through 180° in the vertical plane. The *non-transit* theodolites are either *plain theodolites* or *Y-theodolites* in which the telescope cannot be transited. The *transit* is mainly used and non-transit theodolites have now become obsolete.

6.2. THE ESSENTIALS OF THE TRANSIT THEODOLITE

Fig. 6.1. and 6.2 show diagrammatic sections of a vernier theodolite while Fig. 6.3 shows the photograph of a vernier theodolite. A transit consists of the following essential parts (Ref. Figs. 6.1 and 6.2) :

(*i*) **The Telescope.** The telescope (1) is an integral part of the theodolite and is mounted on a spindle known as horizontal axis or *trunnion axis* (2). The telescope may be internal focusing type or external focusing type. In most of the transits, and internal focusing telescope is used.

(*ii*) **The Vertical Circle.** The vertical circle is a circular graduated arc attached to the trunnion axis of the telescope. Consequently the graduated arc rotates with the telescope when the latter is turned about the horizontal axis. By means of *vertical circle clamp* (24) and its corresponding slow motion or *tangent screw* (25), the telescope can be set accurately at any desired position in vertical plane. The circle is either graduated continuously from 0° to 360 ° in clockwise direction or it is divided into four quadrants (Fig. 6.11).

(*iii*) **The Index Frame** (or **T-Frame** or **Vernier Frame**). The index frame (3) is a T-shaped frame consisting of a vertical leg known as *clipping arm* (28) and a horizontal bar known as vernier arm or *index arm* (29). At the two extremities of the index arm are fitted two verniers to read the vertical circle. The index arm is centered on the trunnion axis in front of the vertical circle and remains *fixed*. When the telescope is moved in

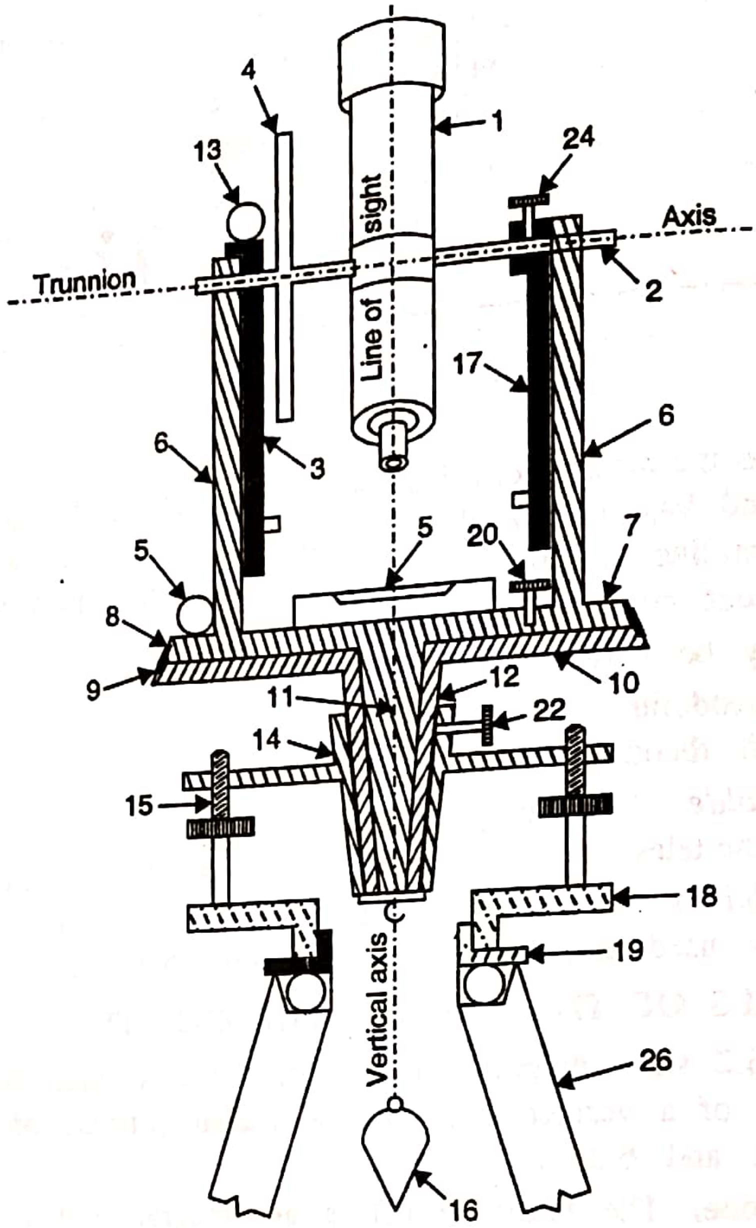

FIG. 6.1. THE ESSENTIALS OF A TRANSIT.

1.	TELESCOPE	13.	ALTITUDE LEVEL
2.	TRUNNION AXIS	14.	LEVELLING HEAD
3.	VERNIER FRAME	15.	LEVELLING SCREW
4.	VERTICAL CIRCLE	16.	PLUMB BOB
5.	PLATE LEVELS	17.	ARM OF VERTICAL CIRCLE CLAMP.
6.	STANDARDS (A-FRAME)	18.	FOOT PLATE
7.	UPPER PLATE	19.	TRIPOD HEAD
8.	HORIZONTAL PLATE VERNIER	20.	UPPER CLAMP
9.	HORIZONTAL CIRCLE	22.	LOWER CLAMP
10.	LOWER PLATE	24.	VERTICAL CIRCLE CLAMP
11.	INNER AXIS	26.	TRIPOD
12.	OUTER AXIS		

the vertical plane, the vertical circle moves relative to the verniers with the help of which reading can be taken. For adjustment purposes, however, the index arm can be rotated slightly with the help of a *clip screw* (27) fitted to the clipping arm at its lower end.

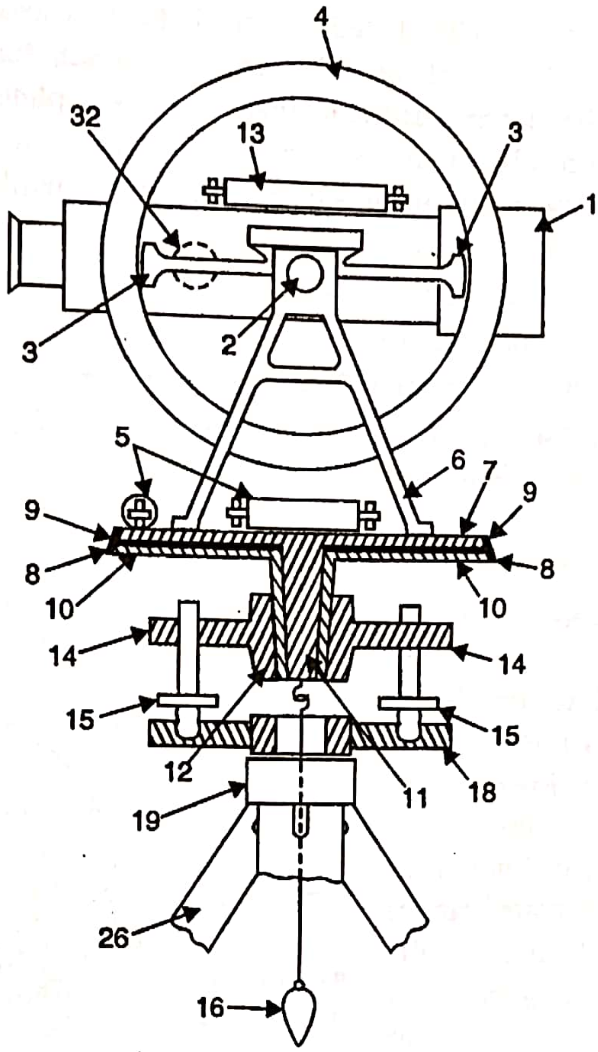

FIG. 6.2. THE ESSENTIALS OF A TRANSIT.

1.	TELESCOPE	11.	INNER AXIS
2.	TRUNNION AXIS	12.	OUTER AXIS
3.	VERNIER FRAME	13.	ALTITUDE LEVEL
4.	VERNIER CIRCLE	14.	LEVELLING HEAD
5.	PLATE LEVELS	15.	LEVELLING SCREW
6.	STANDARDS (A-FRAME)	16.	PLUMB BOB
7.	UPPER PLATE	18.	FOOT PLATE
8.	HORIZONTAL PLATE VERNIER	19.	TRIPOD HEAD
9.	HORIZONTAL CIRCLE	26.	TRIPOD
10.	LOWER PLATE	32.	FOCUSING SCREW

Glass magnifiers (30) are placed in front of each vernier to magnify the reading. A long sensitive bubble tube, sometimes known as the *altitude bubble* (13) is placed on the top of the index frame.

(*iv*) **The Standards** (or **A-Frame**). Two standards (6) resembling the letter A are mounted on the upper plates (7). The trunnion axis of the telescope is supported on these. The T-frame and the *arm of vertical circle clamp* (17) are also attached to the A-frame.

(*v*) **The Levelling Head.** The levelling head (14) usually consists of two parallel triangular plates known as tribrach plates. The upper tribrach has three arms each carrying a levelling screw (15). The lower tribrach plate or foot plate (18) has a circular hole through which a plumb bob (16) may be suspended. In some instruments, four levelling screws (also called foot screws) are provided between two parallel plates. A levelling head has three distinctive functions:

(*a*) To support the main part of the instrument.

(*b*) To attach the theodolite to the tripod.

(*c*) To provide a mean for levelling the theodolite.

(*vi*) **The Two Spindles** (or **Axes** or **Centres**). The *inner spindle or axis* (11) is soild and conical and fits into the outer spindle (12) which is hollow and ground conical in the interior. The inner spindle is also called the upper axis since it carries the vernier or upper plate (7). The outer spindle carries the scale or lower plate (10) and is, therefore, also, known as the lower axis. Both the axes have a common axis which form the vertical axis of the instrument.

(*vii*) **The Lower Plate (or Scale Plate).** The lower plate (10) is attached to the outer spindle. The lower plate carries a horizontal circle (9) at its bevelled edge and is, therefore, also known as the scale plate. The lower plate carries a *lower clamp screw* (22) and a corresponding slow motion or *tangent screw* (23) with the help of which it can be fixed accurately in any desired position. Fig. 6.4 shows a typical arrangement for clamp and tangent screws.

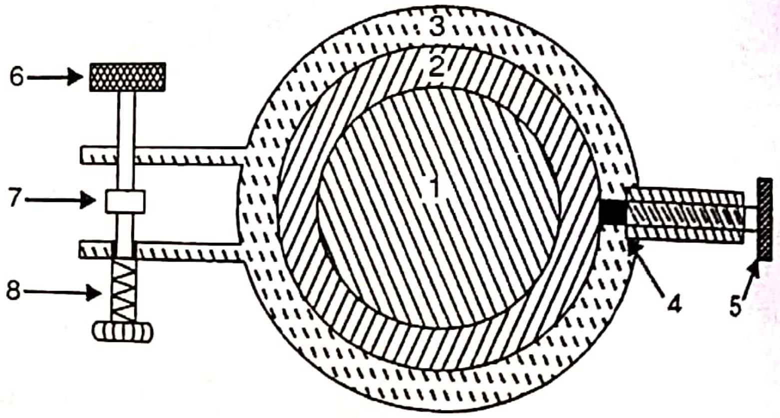

FIG. 6.4. CLAMP AND TANGENT SCREW FOR LOWER PLATE.

1. INNER AXIS
2. OUTER AXIS
3. CASING
4. PAD
5. LOWER CLAMP SCREW
6. TANGENT SCREW
7. LUG ON LEVELLING HEAD
8. ANTAGONISING SPRING.

When the clamp is tightened, the lower plate is fixed to the upper tribrach of the levelling head. On turning the tangent screw, the lower plate can be rotated slightly. Usually, the size of a Theodolite is represented by the size of the scale plate, *i.e.*, a 10 cm theodolite or 12 cm theodolite etc.

(*viii*) **The Upper Plate** (or **Vernier Plate**). The upper plate (7) or vernier plate is attached to the inner axis and carries two verniers (8) with magnifiers (3) at two extremities diametrically opposite. The upper plate supports the standards (6). It carries an *upper clamp screw* (2) and a corresponding *tangent screw* (21) for purpose of *accurately* fixing it to the lower plate. On clamping the upper and unclamping the lower clamp, the instrument can rotate on its outer axis without any relative motion between the two plates. If, however, the lower clamp is clamped and upper clamp unclamped, the upper plate and the instrument can rotate on the inner axis with a relative motion between the vernier and the scale. For using any tangent screw, its corresponding clamp screw must be tightened.

(ix) **The Plate Levels.** The upper plate carries two plate levels (5) placed at right angles to each other. One of the plate level is kept parallel to the trunnion axis. In some theodolites only one plate level is provided. The plate level can be centred with the help of foot screws (15).

(x) **Tripod.** When in use, the theodolite is supported on a tripod (26) which consists of three solid or framed legs. At the lower ends, the legs are provided with pointed steel shoes. The tripod head carries at its upper surface an external screw to which the foot plate (18) of the levelling head can be screwed.

(xi) **The Plumb Bob.** A plumb bob is suspended from the hook fitted to the bottom of the inner axis to centre the instrument exactly over the station mark.

(xii) **The Compass.** Some theodolites are provided with a compass which can be either tubular type or trough type.

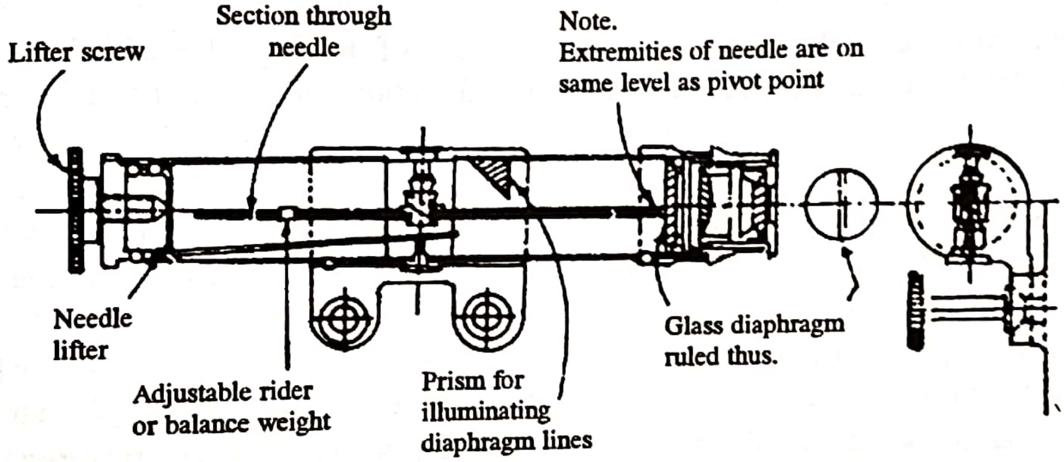

FIG. 6.5. TUBULAR COMPASS.
(BY COURTESY OF MESSRS VICKERS INSTRUMENTS LTD.)

Fig. 6.5 shows a tubular compass for use on a vernier theodolite. The compass is fitted to the standards.

A trough compass consists of a long narrow rectangular box along the longitudinal axis of which is provided a needle balanced upon a steel pivot. Small flat curve scales of only a few degrees are provided on each side of the trough.

(xiii) **Striding Level.** Some theodolites are fitted with a striding level. Fig. 6.6 shows a striding level in position. It is used to test the horizontality of the transit axis or trunnion axis.

6.3. DEFINITIONS AND TERMS

(1) **The vertical axis.** The vertical axis is the axis about which the instrument can be rotated in a horizontal plane. This is the axis about which the lower and upper plates rotate.

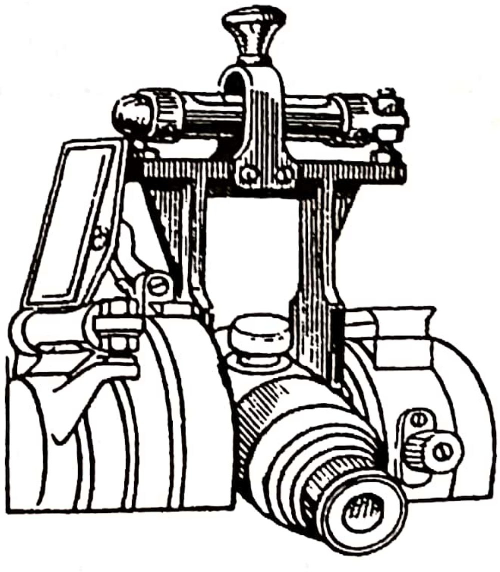

FIG. 6.6.
STRIDING LEVEL IN POSITION.

(2) The horizontal axis. The horizontal or trunnion axis is the axis about which the telescope and the vertical circle rotate in vertical plane.

(3) The line of sight or line of collimation. It is the line passing through the intersection of the horizontal and vertical cross-hairs and the optical centre of the object glass and its continuation.

(4) The axis of level tube. The axis of the level tube or the *bubble line* is a straight line tangential to the longitudinal curve of the level tube at its centre. The axis of the level-tube is horizontal when the bubble is central.

(5) Centring. The process of setting the theodolite exactly over the station mark is known as centring.

(6) Transiting. It is the process of turning the telescope in vertical plane through 180° about the trunnion axis. Since the line of sight is reversed in this operation, it is also known as *plunging* or *reversing*.

(7) Swinging the telescope. It is the process of turning the telescope in horizontal plane. If the telescope is rotated in clock-wise direction, it is known as *right swing*. If telescope is rotated in the anti-clockwise direction, it is known as the *left swing*.

(8) Face left observation. If the face of the vertical circle is to the left of the observer, the observation of the angle (horizontal or vertical) is known as face left observation.

(9) Face right observation. If the face of the vertical circle is to the right of the observer, the observation is known as face right observation.

(10) Telescope normal. A telescope is said to be *normal* or *direct* when the face of the vertical circle is to the left and the "bubble (of the telescope) up".

(11) Telescope inverted. A telescope is said to *inverted* or *reversed* when of the vertical circle is to the right and the "bubble down".

(12) Changing face. It is an operation of bringing the face of the telescope from left to right and *vice versa*.

6.4. TEMPORARY ADJUSTMENTS

Temporary adjustments or *station adjustments* are those which are made at every instrument setting and preparatory to taking observations with the instrument. The temporary adjustments are :

(1) Setting over the station.

(2) Levelling up

(3) Elimination parallax.

(1) Setting up. The operation of setting up includes :

(*i*) *Centring* of the instrument over the station mark by a plumb bob or by optical plummet, and (*ii*) *approximate levelling* with the help of tripod legs. Some instruments are provided with *shifting head* with the help of which accurate centring can be done easily. *By moving the leg radially, the plumb bob is shifted in the direction of the leg while by moving the leg circumferentially or side ways considerable change in the inclination is effected without disturbing the plumb bob.* The second movement is, therefore, effective in the approximate levelling of the instrument. The approximate levelling is done either with reference to a small circular bubble provided on tribrach or is done by eye judgment.

(2) **Levelling up.** After having centred and approximately levelled the instrument, accurate levelling is done with the help of foot screws and with reference to the plate levels. The purpose of the levelling is to make the vertical axis truly vertical. The manner of levelling the instrument by the plate levels depends upon whether there are three levelling screws or four levelling screws.

Three Screw Head. (1) Turn the upper plate until the longitudinal axis of the plate level is roughly parallel to a line joining any two (such as *A* and *B*) of the levelling screws [Fig. 6.7 (*a*)].

(2) Hold these two levelling screws between the thumb and first finger of each hand and turn them uniformly so that the thumbs move either towards each other or away from each other until the bubble is central. *It should be noted that the bubble will move in the direction of movement of the left thumb* [Fig. 6.7 (*a*)].

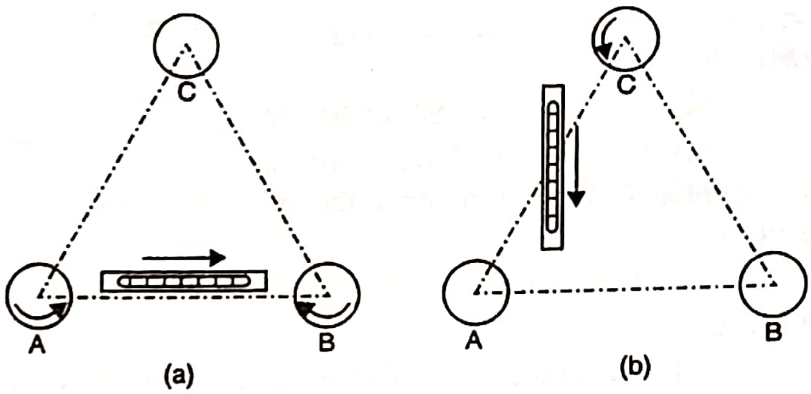

FIG. 6.7. LEVELLING UP WITH THREE FOOT SCREWS.

(3) Turn the upper plate through 90°, *i.e.*, until the axis of the level passes over the position of the third levelling screw *C* [Fig. 6.7 (*b*)].

(4) Turn this levelling screw until the bubble is central.

(5) Return the upper plate through 90° to its original position [Fig. 6.7 (*a*)] and repeat step (2) till the bubble is central.

(6) Turn back again through 90° and repeat step (4).

(7) Repeat steps (2) and (4) till the bubble is central in both the positions.

(8) Now rotate the instrument through 180°. The bubble should remain in the centre of its run, provided it is in correct adjustment. The vertical axis will then be truly vertical. If not, it needs permanent adjustment.

Note. *It is essential to keep to the same quarter circle for the changes in direction and not to swing through the remaining three quarters of a circle to the original position.*

If two plate levels are provided in the place of one, the upper plate is *not* turned through 90° as is done in step (2) above. In such a case, the longer plate level is kept parallel to any two foot screws, the other plate level will automatically be over the third screw. Turn the two foot screws till the longer bubble is central. Turn now the third foot screw till the other bubble is central. The process is repeated till both the bubbles are central. The instrument is now rotated about the vertical axis through a complete revolution. Each bubble will now traverse, *i.e.*, remain in the centre of its run, if they are in adjustment.

Four Screw Head. (1) Turn the upper plate until the longitudinal axis of the plate level is roughly parallel to the line joining two diagonally opposite screws (such as *D* and *B*) [Fig. 6.8 (*a*)].

(2) Bring the bubble central exactly in the same manner as described in step (2) above.

(3) Turn the upper plate through 90 ° until the spirit level axis is parallel to the other two diagonally opposite screws (such as *A* and *C*) [Fig. 6.8 (*b*)].

(4) Centre the bubble as before.

(5) Repeat the above steps till the bubble is central in both the positions.

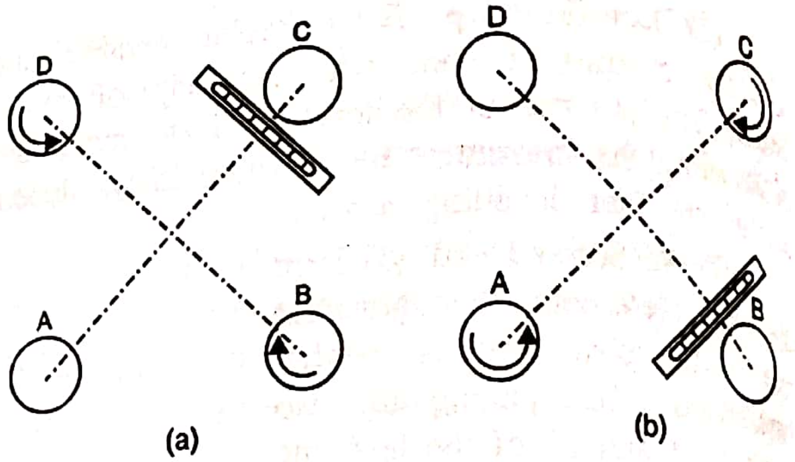

FIG. 6.8. LEVELLING UP WITH FOUR FOOT SCREWS.

(6) Turn through 180° to check the permanent adjustment, as for the three screw instrument.

(3) Elimination of Parallax. Parallax is a condition arising when the image formed by the objective is not in the plane of the cross-hairs. Unless parallax is eliminated, accurate sighting is impossible. Parallax can be eliminated in two steps : (*i*) by focusing the eye-piece for distinct vision of the cross-hairs, and (*ii*) by focusing the objective to bring the image of the object in the plane of cross-hairs.

(*i*) ***Focusing the eye-piece.*** To focus the eye-piece for distinct vision of the cross-hairs, point the telescope towards the sky (or hold a sheet of white paper in front of the objective) and move eye-piece in or out till the cross-hairs are seen sharp and distinct. In some telescopes, graduations are provided at the eye-piece end so that one can always remember the particular graduation position to suit his eyes. This may save much of time.

(*ii*) ***Focusing the objective.*** The telescope is now directed towards the object to be sighted and the focusing screw is turned till the image appears clear and sharp. The image so formed is in the plane of cross-hairs.

6.5. MEASUREMENT OF HORIZONTAL ANGLES : GENERAL PROCEDURE

To measure the horizontal angle *PQR* (Fig. 6.9) :

(1) Set up the instrument at *Q* and level it accurately.

(2) Release all clamps. Turn the upper and lower plates in opposite directions till the zero of one of the vernier (say *A*) is against the zero of the scale and the vertical circle is to the left. Clamp both the plates together by upper clamp and lower clamp and bring the two zeros into exact coincidence by turning the upper tangent screw. Take both vernier readings. The reading on vernier *B* will be 180°, if there is no instrumental error.

(3) Loose the lower clamp and turn the instrument towards the signal at *P*. Since both the plates are clamped together, the instrument will rotate about the outer axis. Bisect point *P* accurately by using lower tangent screw. Check the readings of verniers *A* and *B*. There should be no change in the previous reading.

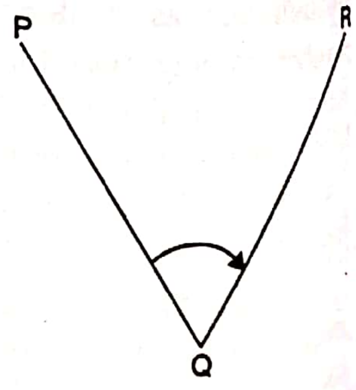

FIG. 6.9.

(4) Unclamp the upper clamp and rotate the instrument clockwise about the inner axis to bisect the point R. Clamp the upper clamp and bisect R accurately by using upper tangent screw. (The point of intersection of the horizontal and vertical cross-hairs should be brought into exact coincidence with the station mark by means of vertical circle clamp and tangent screw).

(5) Read both verniers. The reading of vernier A gives the angle PQR directly while the vernier B gives by deducting 180°. While entering the reading, the full reading of vernier A (*i.e.*, degrees, minutes and seconds) should be entered, while only minutes and seconds of the vernier B are entered. The mean of the two such vernier readings gives angle with one face.

(6) Change the face by transiting the telescope and repeat the whole process. The mean of the two vernier readings gives the angle with other face.

The average horizontal angle is then obtained by taking the mean of the two readings with different faces. Table 6.1 gives the specimen page for recording the observations.

TO MEASURE A HORIZONTAL ANGLE BY REPETITION METHOD

The method of repetition is used to measure a horizontal angle to a finer degree of accuracy than that obtainable with the least count of the vernier. By this method, an angle is measured two or more times by allowing the vernier to remain clamped each time at the end of each measurement instead of setting it back at zero when sighting at the previous station. Thus an angle reading is mechanically added several times depending upon the number of repetitions. The average horizontal angle is then obtained by dividing the final reading by the number of repetitions.

To measure the angle PQR (Fig. 6.9) :

(1) Set the instrument at Q and level it. With the help of upper clamp and tangent screw, set 0° reading on vernier A. Note the reading of vernier B.

(2) Loose the lower clamp and direct the telescope towards the point P. Clamp the lower clamp and bisect point P accurately by lower tangent screw.

(3) Unclamp the upper clamp and turn the instrument *clockwise* about the inner axis towards R. Clamp the upper clamp and bisect R accurately with the upper tangent screw. Note the reading of verniers A and B to get the approximate value of the angle PQR.

(4) Unclamp the lower clamp and turn the telescope clockwise to sight P again. Bisect P accurately by using the lower tangent screw. *It should be noted that the vernier readings will not be changed in this operation since the upper plate is clamped to the lower.*

(5) Unclamp the upper clamp, turn the telescope clockwise and sight R. Bisect R accurately by upper tangent screw.

(6) Repeat the process until the angle is repeated the required number of times (usually 3). The average angle with face left will be equal to final reading divided by three.

(7) Change face and make three more repetitions as described above. Find the average angle with face right, by dividing the final reading by three.

(8) The average horizontal angle is then obtained by taking the average of the two angles obtained with face left and face right.

TABLE 6.1.

Instrument At	Sighted to	Face : Left								Swing : Right				Face : Right								Swing : Right				Average Horizontal Angle		
		A			B		Mean			No. of Repetitions	Horizontal Angle			A			B		Mean			No. of Repetitions	Horizontal Angle					
		°	'	"	'	"	°	'	"		°	'	"	°	'	"	'	"	°	'	"		°	'	"	°	'	"
Q	P	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0							
	R	52	41	20	41	20	52	41	20	1	52	41	20	52	41	40	41	40	52	41	40	1	52	41	40	52	41	30

TABLE 6.2 REPETITION METHOD

Q	P	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0							
	R	52	41	20	41	20	52	41	20	1				52	41	40	41	40	52	41	40	1						
	R	158	04	40	04	40	158	04	40	3	52	41	33	158	04	40	04	40	158	04	40	3	52	41	33	52	41	33

Any number of repetitions may be made. However, three repetitions with the telescope normal and three with the telescope inverted are quite sufficient for any thing except very precise work. Table 6.2 gives the method of recording observations by method of repetition for ordinary work.

'Sets' by Method of Repetition for High Precision

For measuring an angle to the highest degree of precision, several *sets* of repetitions are usually taken. *There are two methods of taking a single set.*

First Method **:** (1) Keeping the telescope normal throughout, measure the angle *clockwise* by 6 repetitions. Obtain the *first value* of the angle by dividing the final reading by 6.

(2) Invert the telescope and measure the angle *counter-clockwise* by 6 repetitions. Obtain the *second value* of the angle by dividing the final reading by 6.

(3) Take the mean of the first and second values to get the average value of the angle by *first set.*

Take as many sets in this way as may be desired. For first order work, five or six sets are usually required. The final value of the angle will be obtained by taking the mean of the values obtained by different sets.

Second Method **:** (1) Measure the angle clockwise by six repetitions, the first three with the telescope normal and the last three with the telescope inverted. Find the *first value* of the angle by dividing the final by six.

(2) Without altering the reading obtained in the sixth repetition, measure the explement of the angle (*i.e.* 360° – *PQR*) *clockwise* by six repetitions, the first three with telescope inverted and the last three with telescope normal. Take the reading which should theoretically by equal to zero (or the initial value). If not, note the error and distribute half the error to the *first value* of the angle. *The result is the corrected value of the angle by the first set.* Take as many sets as are desired and find the average angle. For more accurate work, the initial reading at the beginning of each set may not be set to zero but to two different values.

Note. *During an entire set of observations, the transit should not be relevelled.*

Elimination of Errors by Method of Repetition

The following errors are eliminated by method of repetition:

(1) Errors due to eccentricity of verniers and centres are eliminated by taking both vernier readings.

(2) Errors due to inadjustments of line of collimation and the trunnion axis are eliminated by taking both face readings.

(3) The error due to inaccurate graduations are eliminated by taking the readings at different parts of the circle.

(4) Errors due to inaccurate bisection of the object, eccentric centring etc., may be to some extent counter-balanced in different observations.

It should be noted, however, that in repeating angles, operations such as sighting and clamping are multiplied and hence opportunities for error are multiplied. The limit of precision in the measurement of an angle is ordinarily reached after the fifth or sixth repetition.

Errors due to slip, displacement of station signals, and want of verticality of the vertical axis etc., are not eliminated since they are all cumulative.

TO MEASURE A HORIZONTAL ANGLE BY DIRECTION METHOD (OR REITERATION METHOD)

The method known as *'direction method'* or *reiteration method* or *method of series* is suitable for the measurements of the angles of a group having a common vertex point. Several angles are measured successively and finally the *horizon is closed.* (Closing the horizon is the process of measuring the angles around a point to obtain a check on their sum, which should equal 360°).

To measure the angles *AOB, BOC, COD* etc., by reiteration, proceed as follows (Fig. 6.10).

(1) Set the instrument over *O* and level it. Set one vernier to zero and bisect point *A* (or any other reference object) accurately.

(2) Loose the upper clamp and turn the telescope clockwise to point *B*. Bisect *B* accurately using the upper tangent screw. Read both the verniers. The mean of the vernier readings will give the angles *AOB*.

(3) Similarly, bisect successively, *C, D,* etc., thus closing the circle. Read both the verniers at each bisection. Since the graduated circle remains in a fixed position throughout the entire process, each included angle is obtained by taking the difference between two consecutive readings.

(4) On final sight to *A*, the reading of the vernier should be the same as the original setting. It not, note the reading and find the error due to slips etc., and if the error is small, distribute it *equally* to all angles. If large, repeat the procedure and take a fresh set of readings.

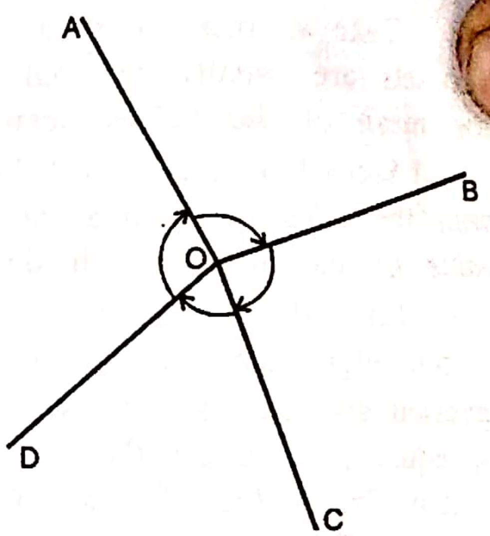

FIG. 6.10.

(5) Repeat steps 2 to 4 with the other face.

Table 6.3 illustrates the method of recording the observations.

Sets by the Direction Method. For precise work, several sets of readings are taken. The procedure for each set is as follows :

(1) Set zero reading on one vernier and take a back sight on *A*. Measure *clockwise* the angles *AOB, BOC, COD, DOA,* etc., exactly in the same manner as explained above and close the horizon. Do not distribute the error.

(2) Reverse the telescope, unclamp the lower clamp and back sigh on *A*. Take reading and foresight on *D, C, B* and *A*, in *counter-clockwise* direction and measure angles *AOD, DOC, COB* and *BOA.*

From the two steps, two values of each of the angles are obtained. The mean of the two is taken as the average value of each of the uncorrected angles. The sum of all the average angles so found should be 360°. In the case of discrepancy, the error (if small) may be distributed equally to all the angles. The values so obtained are the

TABLE 6.3.
REITERATION METHOD

Instrument at	Sighted to	Face : Left								Swing : Right			Face : Right								Swing : Left			Average Horizontal Angle		
		A			B		Mean			Horizontal Angle			A			B		Mean			Horizontal Angle					
		°	′	″	′	″	°	′	″	°	′	″	°	′	″	′	″	°	′	″	°	′	″	°	′	″
O	A	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0						
	B	54	31	20	31	20	54	31	20	*AOB* 54	31	20	54	31	40	31	40	54	31	40	54	31	40	54	31	30
	C	102	25	40	25	40	102	25	40	*BOC* 47	54	20	102	26	00	26	00	102	26	00	47	54	20	47	54	20
	D	239	49	40	49	40	239	40	40	*COD* 137	24	00	239	49	49	49	40	239	49	40	137	23	40	137	23	50
	A	360	0	0	0	0	360	0	0	*DOA* 120	10	20	360	0	0	0	0	360	0	0	120	10	20	120	10	20

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corrected values for the *first set*. Several such sets may be taken by setting the initial angle on the vernier to different values.

The number of *sets* (or positions, as is sometimes called) depends on the accuracy required. For first order triangulation, *sixteen* such sets are required with a 1" direction theodolite, while for second order triangulation, *four* and for third order triangulation two. For ordinary work, however, one set is sufficient.

6.6. MEASUREMENT OF VERTICAL ANGLES

Vertical angle is the angle which the inclined line of sight to an object makes with the horizontal. It may be an angle of elevation or angle of depression depending upon whether the object is above or below the horizontal plane passing through the trunnion axis of the instrument. To measure a vertical angle, the instrument should be levelled with reference to the altitude bubble. *When the altitude bubble is on the index frame, proceed as follows :*

(1) Level the instrument with reference to the plate level, as already explained.

(2) Keep the altitude level parallel to any two foot screws and bring the bubble central. Rotate the telescope through 90° till the altitude bubble is on the third screw. Bring the bubble to the centre with the third food screw. Repeat the procedure till the bubble is central in both the positions. If the bubble is in adjustment it will remain central for all pointings of the telescope.

(3) Loose the vertical circle clamp and rotate the telescope in vertical plane to sight the object. Use vertical circle tangent screw for accurate bisection.

(4) Read both verniers (*i.e.* C and D) of vertical circle. The mean of the two gives the vertical circle. Similar observation may be made with another face. The average of the two will give the required angle.

Note. *It is assumed that the altitude level is in adjustment and that index error has been eliminated by permanent adjustments. The clip screw should not be touched during these operations.*

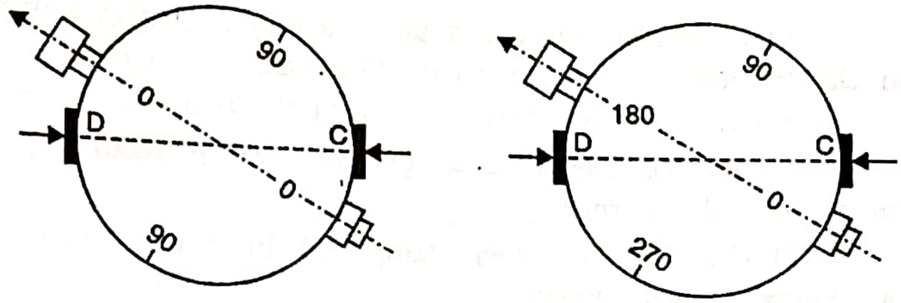
In some instruments, the altitude bubble is provided both on index frame as well as on the telescope. In such cases, the instrument is levelled with reference to the altitude bubble on the index frame and *not* which reference to the altitude bubble on the telescope. Index error will be then equal to the reading on the vertical circle when the bubble on the telescope is central. If, however, the theodolite is to be used as a level, it is to be levelled with reference to the altitude bubble placed on the telescope.

If it is required to measure the vertical angle between two points A and B as subtended at the trunnion axis, sight first the higher point and take the reading of the vertical circle. Then sight the lower point and take the reading. The required vertical angle will be equal to the algebraic difference between the two readings taking angle of elevation as positive and angle of depression as negative. Table 6.4 illustrates the method of recording the observations.

Graduations on Vertical Circle

Fig. 6.11 shows two examples of vertical circle graduations. In Fig. 6.11.(*a*), the circle has been divided into four quadrants. Remembering that the vernier is fixed while circle is moved with telescope, it is easy to see how the readings are taken.

For an elevated line of sight with face left, verniers C and D read 30° (say) as angle of elevation. In Fig. 6.11 (*b*), the circle is divided form 0° to 360° with zero at vernier C. For angle of elevation with face left, vernier C reads 30° while D reads 210° . In this system, therefore, 180° are to be deducted from vernier D to get the correct reading. However, it is always advisable to take full reading (*i.e.*, degrees, minutes and seconds) on one vernier and part reading (*i.e.*, minutes and seconds) of the other.



(a) (b)

FIG. 6.11. EXAMPLES OF VERTICAL CIRCLE GRADUATION.

TABLE 6.4 VERTICAL ANGLES

Instrument at	Sighted to	Face : Left											Face : Right											Average Vertical Angle		
		C			D		Mean			Vertical Angle			C			D		Mean			Vertical Angle					
		°	′	″	′	″	°	′	″	°	′	″	°	′	″	′	″	°	′	″	°	′	″	°	′	″
O	*A*	−5	12	20	12	00	−5	12	10				−5	12	40	12	20	−5	12	30						
	B	+2	25	40	25	20	+2	25	30	7	37	40	+2	26	00	25	40	+2	25	50	7	38	20	7	38	00

6.7. MISCELLANEOUS OPERATIONS WITH THEODOLITE

1. TO MEASURE MAGNETIC BEARING OF A LINE

In order to measure the magnetic bearing of a line, the theodolite should be provided with either a tubular compass or trough compass. The following are the steps (Fig. 6.12):

(1) Set the instrument at P and level it accurately.

(2) Set accurately the vernier A to zero.

(3) Loose the lower clamp. Release the needle of the compass. Rotate the instrument about its outer axis till the magnetic needle roughly points to north. Clamp the lower clamp. Using the lower tangent screw, bring the needle exactly against the mark so that it is in magnetic meridian. The line of sight will also be in the magnetic meridian.

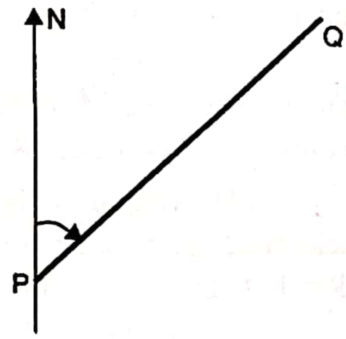


FIG. 6.12.

(4) Loose the upper clamp and point the telescope towards Q. Bisect Q accurately using the upper tangent screw. Read verniers A and B.

(5) Change the face and repeat steps 2, 3 and 4. The average of the two will give the correct bearing of the line PQ.

2. TO MEASURE DIRECT ANGLES

(4) Measure angle PQR_1 by method of repetition. Let angle PQR_1 (by six repetition) be 274° 3′ 20″. The average value of the angle PQR_1 will be $\frac{274° 3' 20''}{6} = 45° 40' 33''$.

(5) The angle PQR_1 is now to be corrected by an angular amount R_1QR to establish the true angle PQR. Since the correction (*i.e.* 45° 40′ 33″ − 45° 40′ 16″ = 17″) is very small, it is applied linearly by making offset $R_1R = QR_1 \tan R_1QR$. Measure QR_1. Let it be 200 m. Then, $R_1R = 200 \tan 17'' = 0.017$ m (taking tan 1′ = 0.0003 nearly). Thus, point R is established by making $R_1 R = 0.017$ m

(6) As a check, measure $\angle PQR$ again by repetition.

6.8. FUNDAMENTAL LINES AND DESIRED RELATIONS

The *fundamental lines* of a transit are :

(1) The vertical axis.
(2) The horizontal axis (or trunnion axis or transit axis).
(3) The line of collimation (or line of sight).
(4) Axis of plate level.
(5) Axis of altitude level.
(6) Axis of the striding level, if provided.

Desired Relations : Fig. 6.22 shows the relationship between the line of sight, the axes and the circles of the theodolite. The following relationship should exist :

(1) The axis of the plate level must lie in a plane perpendicular to the vertical axis.

If this condition exists, the vertical axis will be truly vertical when the bubble is in the centre of its run.

(2) The line of collimation must be perpendicular to the horizontal axis at its intersection

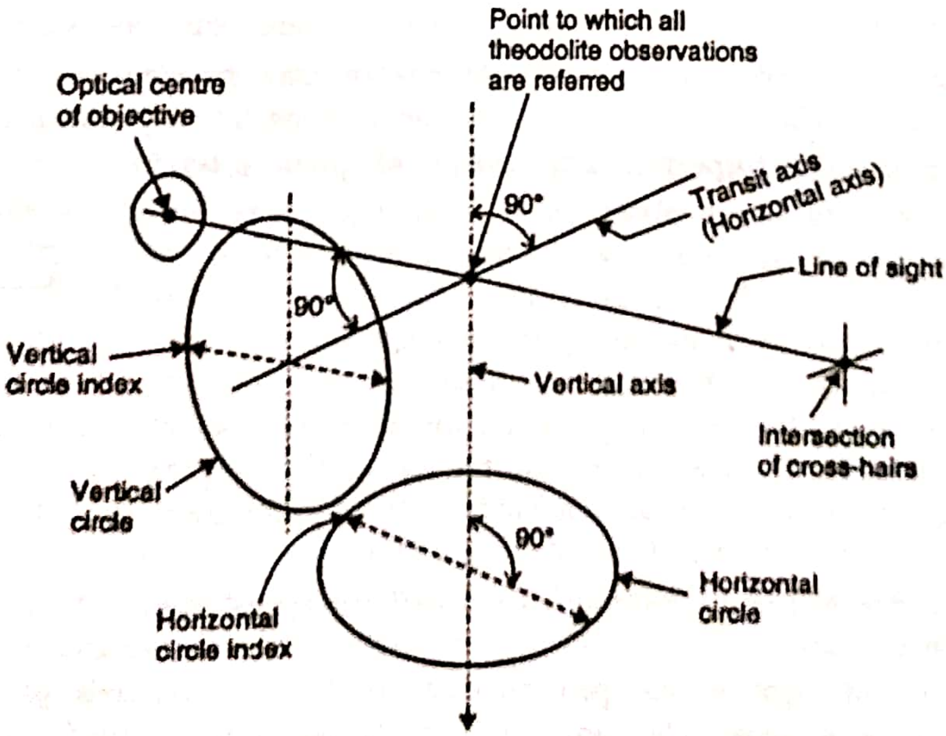


FIG. 6.22. LINE OF SIGHT, AXES AND CIRCLES OF THE THEODOLITE.

with the vertical axis. Also, if the telescope is external focusing type, the optical axis, the axis of the objective slide and the line of collimation must coincide.

If this condition exists, the line of sight will generate a vertical plane when the telescope is rotated about the horizontal axis.

(3) The horizontal axis must be perpendicular to the vertical axis.

If this condition exists, the line of sight will generate a vertical plane when the telescope is plunged.

(4) The axis of the altitude level (or telescope level) must be parallel to line of collimation.

If this condition exists, the vertical angles will be free from index error due to lack of parallelism.

(5) The vertical circle vernier must read zero when the line of collimation is horizontal.

If this condition exists, the vertical angles will be free from index error due to displacement of the vernier.

(6) The axis of the striding level (if provided) must be parallel to the horizontal axis.

If this condition exists, the line of sight (if in adjustment) will generate a vertical plane when the telescope is plunged, the bubble of striding level being in the centre of its run.

6.9. SOURCES OF ERROR IN THEODOLITE WORK

The sources of error in transit work are :

(1) Instrumental (2) Personal, and (3) Natural.

1. INSTRUMENTAL ERRORS

The instrumental errors are due to (*a*) imperfect adjustment of the instrument, (*b*) structural defects in the instrument, and (*c*) imperfections due to wear.

The total instrumental error to an observation may be due solely to one or to a combination of these. The following are errors due to imperfect adjustment of the instrument.

(*i*) Error due to imperfect adjustment of plate levels

If the upper and lower plates are not horizontal when the bubbles in the plate levels are centred, the vertical axis of the instrument will not be truly vertical (Fig. 6.23). The horizontal angles will be measured in an inclined plane and not in a horizontal plane. The vertical angles measured will also be incorrect. The error may be serious in observing the points the difference in elevation of which is considerable. The error can be eliminated only by careful levelling with respect to the altitude bubble if it is in adjustment. The errors cannot be eliminated by double sighting.

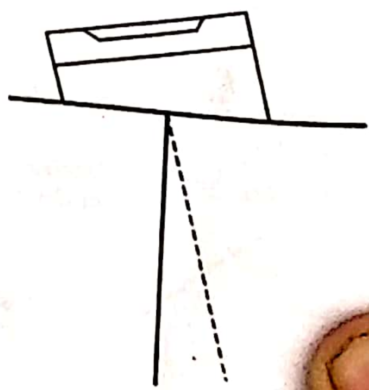


FIG. 6.23

(*ii*) Error due to line of collimation not being perpendicular to the horizontal axis.

If the line of sight is not perpendicular to the trunnion axis of the telescope, it will not revolve in a plane when the telescope is raised or lowered but instead, it will