standard gear is mounted on a fixed frame, while the gear being inspected is fixed to a sliding carriage. The two gears are mounted on mandrels, which facilitate accurate mounting of gears in machines, so that a dial indicator will primarily measure irregularities in the gear under inspection. A dial indicator of high resolution is used to measure the composite error, which reflects errors due to runout, tooth-to-tooth spacing, and profile variations.

![Parkinson gear tester](image)

To start with, the two gears are mounted on respective mandrels and the slide comprising the standard gear is fixed at a convenient position. The sliding carriage is moved along the table, the two gears are brought into mesh, and the sliding carriage base is also locked in its position. Positions of the two mandrels are adjusted in such a way that their axial distance is equal to the gear centre distance as per drawings. However, the sliding carriage is free to slide for a small distance on steel rollers under a light spring force. A vernier scale attached to the machine enables measurement of the centre distance up to 25 µm. The dial indicator is set to zero and the gear under inspection is rotated. Radial variations of the gear being inspected are indicated by the dial indicator. This variation is plotted on a chart or graph sheet, which indicates the radial variations in the gear for one complete rotation.

Many improvisations are possible to the basic machine explained in Section 8.5.1. A waxed paper recorder can be fitted to the machine so that a trace of the variations of a needle in contact with the sliding carriage is made simultaneously. The mechanism can be designed to provide a high degree of magnification.

### 8.6 MEASUREMENT OF SCREW THREADS

Screw thread geometry has evolved since the early 19th century, thanks to the importance of threaded fasteners in machine assemblies. The property of interchangeability is associated more strongly with screw threads than with any other machine part. Perhaps, the *Whitworth thread system*, proposed as early as the 1840s, was the first documented screw thread profile that came into use. A couple of decades later, the *Sellers system* of screw threads came into use in the United States. Both these systems were in practice for a long time and laid the foundation for a more comprehensive *unified screw thread system*.

Screw thread gauging plays a vital role in industrial metrology. In contrast to measurements of geometric features such as length and diameter, screw thread measurement is more complex. We need to measure inter-related geometric aspects such as pitch diameter, lead, helix, and flank angle, among others. The following sections introduce screw thread terminology and
discuss the measurements of screw thread elements and thread gauging, which speeds up the inspection process.

8.7 SCREW THREAD TERMINOLOGY

Figure 8.20 illustrates the various terminologies associated with screw threads.

Screw thread The American Society of Tool and Manufacturing Engineers (ASTME) defines a screw thread as follows: screw thread is the helical ridge produced by forming a continuous helical groove of uniform section on the external or internal surface of a cylinder or cone.

Form of thread This is the shape of the contour of one complete thread, as seen in an axial section. Some of the popular thread forms are British Standard Whitworth, American Standard, British Association, Knuckle, Buttress, Unified, Acme, etc.

External thread The screw thread formed on the external surface of a workpiece is called an external thread. Examples of this include bolts and studs.

Internal thread The screw thread formed on the internal surface of a workpiece is called an internal thread. The best example for this is the thread on a nut.

Axis of thread (pitch line) This is the imaginary line running longitudinally through the centre of the screw.

Fundamental triangle It is the imaginary triangle that is formed when the flanks are extended till they meet each other to form an apex or a vertex.

Angle of thread This is the angle between the flanks of a thread measured in the axial plane. It is also called an included angle.

Flank angle It is the angle formed between a flank of the thread and the perpendicular to the axis of the thread that passes through the vertex of the fundamental triangle.

![Screw thread terminology diagram]

**Legend**

1: Angular pitch
2: Pitch
3: Major diameter
4: Pitch diameter
5: Minor diameter
6: Pitch line
7: Apex
8: Root
9: Crest
10: Addendum
11: Dedendum
12: Depth of thread
\( \theta \): Angle of thread
\( \alpha \): Flank angle

*Fig. 8.20* Screw thread terminology
**Pitch**  It is the distance between two corresponding points on adjacent threads, measured parallel to the axis of the thread.

**Lead**  It is the axial distance moved by the screw when the crew is given one complete revolution about its axis.

**Lead angle**  It is the angle made by the helix of the thread at the pitch line with the plane perpendicular to the axis.

**Helix angle**  It is the angle made by the helix of the thread at the pitch line with the axis. This angle is measured in an axial plane.

**Major diameter**  In case of external threads, the major diameter is the diameter of the major cylinder (imaginary), which is coaxial with the screw and touches the crests of an external thread. For internal threads, it is the diameter of the cylinder that touches the root of the threads.

**Minor diameter**  In case of external threads, the minor diameter is the diameter of the minor cylinder (imaginary), which is coaxial with the screw and touches the roots of an external thread. For internal threads, it is the diameter of the cylinder that touches the crests of the threads. It is also called the root diameter.

**Addendum**  It is the radial distance between the major diameter and pitch line for external threads. On the other hand, it is the radial distance between the minor diameter and pitch line for internal threads.

**Dedendum**  It is the radial distance between the minor diameter and pitch line for external threads. On the other hand, it is the radial distance between the major diameter and pitch line for internal threads.

**Effective diameter or pitch diameter**  It is the diameter of the pitch cylinder, which is coaxial with the axis of the screw and intersects the flanks of the threads in such a way as to make the widths of threads and the widths of spaces between them equal. In general, each of the screw threads is specified by an effective diameter as it decides the quality of fit between the screw and a nut.

**Single-start thread**  In case of a single-start thread, the lead is equal to the pitch. Therefore, the axial distance moved by the screw equals the pitch of the thread.

**Multiple-start thread**  In a multiple-start thread, the lead is an integral multiple of the pitch. Accordingly, a double start will move by an amount equal to two pitch lengths for one complete revolution of the screw.

---

### 8.8 Measurement of Screw Thread Elements

Measurement of screw thread elements is necessary not only for manufactured components, but also for threading tools, taps, threading hobs, etc. The following sections discuss the methods for measuring major diameter, minor diameter, effective diameter, pitch, angle, and form of threads.
8.8.1 Measurement of Major Diameter

The simplest way of measuring a major diameter is to measure it using a screw thread micrometer. While taking readings, only light pressure must be used, as the anvils make contact with the screw solely at points and any excess application of pressure may result in a slight deformation of anvil due to compressive force, resulting in an error in the measurement. However, for a more precise measurement, it is recommended to use a bench micrometer shown in Fig. 8.21.

A major advantage of a bench micrometer is that a fiducial indicator is a part of the measuring system. It is thus possible to apply a pressure already decided upon by referring to the fiducial indicator. However, there is no provision for holding the workpiece between the centres, unlike a floating carriage micrometer. The inspector has to hold the workpiece by hand while the readings are being taken.

The machine is essentially used as a comparator. To start with, the anvil positions are set by inserting a setting cylinder. A setting cylinder serves as a gauge and has a diameter that equals the OD of the screw thread being inspected. Now, the setting cylinder is taken out, the workpiece is inserted between the anvils, and the deviation is noted down on the micrometer head. Since the position of the fixed anvil will remain unaltered due to the setting of the fiducial arrangement, the movable anvil will shift axially depending on the variation in the value of OD of the screw being inspected. In order to sense deviations on either side of the preset value, the movable anvil will always be set to a position, which can detect small movements in either direction. The error, as measured by the micrometer head, is added to or subtracted from, as the case may be, the diameter of the setting cylinder to get the actual value of OD.

Measurement of the OD of internal threads is trickier, as it is cumbersome to take measurements using conventional instruments. An easier option is to employ some indirect measurement techniques. A cast of the thread is made, which results in a male counterpart of the internal thread. Now, the measurement can be carried out using techniques used for external threads. The cast may be made of plaster of Paris or wax.

8.8.2 Measurement of Minor Diameter

The best way of measuring a minor diameter is to measure it using a floating carriage micrometer described in Chapter 4. The carriage has a micrometer with a fixed spindle on one side and a movable spindle with a micrometer on the other side. The carriage moves on a finely ground ‘V’ guideway or an anti-friction guideway to facilitate movement in a direction parallel to the axis of the plug gauge mounted between centres.
The micrometer has a non-rotary spindle with a least count of up to 0.001 or 0.002 mm. The instrument is very useful for thread plug gauge manufacturers; in gauge calibration laboratories, established under NABL accreditation; and in standard rooms where in-house gauge calibration is carried out.

Minor diameter is measured by a comparative process, wherein small V-pieces that make contact at the root of the threads are used. The selection of V-pieces should be such that the included angle of a V-piece is less than the angle of the thread. V-pieces are placed on each side of the screw with their bases against the micrometer faces. As in the previous case, the initial reading is taken by mounting a setting cylinder corresponding to the dimension being measured. Then, the threaded workpiece is mounted between the centres and the reading is taken. The difference in the two readings directly gives the error in the minor diameter.

### 8.8.3 Measurement of Effective Diameter

In Section 8.7 we defined an effective diameter of a screw thread as the diameter of the pitch cylinder, which is coaxial with the axis of the screw and intersects the flanks of the threads in such a way so as to make the width of threads and widths of spaces between them equal. Since it is a notional value, it cannot be measured directly and we have to find the means of measuring it in an indirect way. Thread measurement by wire method is a simple and popular way of measuring an effective diameter. Small, hardened steel wires (best-size wire) are placed in the thread groove, and the distance over them is measured as part of the measurement process. There are three methods of using wires: one-wire, two-wire, and three-wire methods.

**One-wire Method**

This method is used if a standard gauge of the same dimension as the theoretical value of dimension over wire is available. First of all, the micrometer anvils are set over the standard gauge and the dimension is noted down. Thereafter, the screw to be inspected is held either in hand or in a fixture, and the micrometer anvils are set over the wire as shown in Fig. 8.22.

Micrometer readings are taken at two or three different locations and the average value is calculated. This value is compared with the value obtained with the standard gauge. The resulting difference is a reflection of error in the effective diameter of the screw. An important point to be kept in mind is that the diameter of the wire selected should be such that it makes contact with the screw along the pitch cylinder. The significance of this condition will become obvious in the two-wire method explained in the next section.

**Two-wire Method**

In this method, two steel wires of identical diameter are placed on opposite flanks of a screw, as shown in Fig. 8.23.

The distance over wires \((M)\) is measured using a suitable micrometer. Then, the effective diameter,

\[
D_e = T + P
\]

(8.4)

where \(T\) is the dimension under the wires and \(P\) is the correction factor.

And,
\[ T = M - 2d \]  \hspace{1cm} (8.5)

where \( d \) is the diameter of the best-size wire.

These relationships can be easily derived by referring to Fig. 8.24.

The two wires of identical diameter are so selected that they make contact with the screw thread on the pitch line. The aforementioned equations are valid only if this condition is met.

Accordingly, from triangle OFD,\( \overline{OF} = \frac{d}{2}\csc\left(\frac{x}{2}\right) \)

\[ \overline{FA} = \frac{d}{2}\csc\left(\frac{x}{2}\right) - \frac{d}{2} = \frac{d}{2}\left[\csc\left(\frac{x}{2}\right) - 1\right] \]

\[ \overline{FG} = \overline{GC}\cot\left(\frac{x}{2}\right) = \frac{p}{4}\cot\left(\frac{x}{2}\right) \quad \text{(because \( \overline{BC} = \text{pitch}/2 \) and \( \overline{GC} = \text{pitch}/4 \))} \]

Therefore, \( \overline{AG} = \overline{FG} - \overline{FA} = \frac{p}{4}\cot\left(\frac{x}{2}\right) - \frac{d}{2}\left[\csc\left(\frac{x}{2}\right) - 1\right] \)

Since \( \overline{AG} \) accounts for the correction factor only on one side of the screw, we have to multiply this value by 2 in order to account for that on the opposite flank.

Therefore, total correction factor is as follows:

\[ P = 2\overline{AG} = \frac{p}{2}\cot\left(\frac{x}{2}\right) - d\left[\csc\left(\frac{x}{2}\right) - 1\right] \quad (8.6) \]

Although it is possible to measure the value of \( M \), the distance over the wires, using a hand-held micrometer, this method is prone to errors. A better alternative is to use a floating carriage micrometer shown in Fig. 4.41 of Chapter 4, which helps in aligning the micrometer square to the thread, enabling more accurate readings.

**Diameter of Best-size Wire**

The best-size wire, of diameter \( d \), makes contact with the thread flank along the pitch line.
Equations (8.4)–(8.6) hold true if this condition is met. Figure 8.25 illustrates the condition achieved by the best-size wire.

In triangle OAB, \( \sin (AOB) = AB/OB \)
that is, \( \sin (90 - x/2) = AB/OB \)
or, \( OB = \frac{AB}{\sin (90 - x/2)} = \frac{AB}{\cos (x/2)} = AB \sec (x/2) \)

Diameter of the best-size wire = \( 2(AB) = 2(AB) \sec (x/2) \).
However, from Fig. 8.25, \( AB = p/4 \), where \( p \) is the pitch of the thread.
Therefore, diameter of the best-size wire is
\[
d = \frac{p}{2} \sec \left( \frac{x}{2} \right) \quad (8.7)
\]

**Three-wire Method**

The three-wire method is an extension of the principle of the two-wire method. As illustrated in Fig. 8.26, three wires are used to measure the value of \( M \), one wire on one side and two wires on adjacent thread flanks on the other side of the screw. Measurement can be made either by holding the screw, wires, and micrometer in hand or by using a stand with an attachment to hold the screw in position. Since three wires are used, the micrometer can be positioned more accurately to measure \( M \), the distance over the wires.

With reference to Fig. 8.27, let \( M \) be the distance over the wires, \( E \) the effective diameter of the screw, \( d \) the diameter of best-size wires, and \( H \) the height of threads.

Now, \( OC = OA \cosec (x/2) = \frac{d}{2} \cosec (x/2) \quad (8.8) \)

\( H = \frac{p}{2} \cot (x/2) \) and, therefore, \( BC = H/2 \)
\[
= \frac{p}{4} \cot \left( \frac{x}{2} \right) \quad (8.9)
\]

If \( h \) is the height of the centre of wire from the pitch line, then \( h = OC - BC \).
\[
h = \frac{d}{2} \cosec \left( \frac{x}{2} \right) - \frac{p}{4} \cot \left( \frac{x}{2} \right) \quad (8.10)
\]

Distance over wires, \( M = E + 2h + 2r \), where \( r \) is the radius of the wires.

Therefore, effective diameter
\[
E = M - d \cosec \left( \frac{x}{2} \right) + \frac{p}{2} \cot \left( \frac{x}{2} \right) - d
\]
\[
E = M - d[1 + \cosec \left( \frac{x}{2} \right)] + \frac{p}{2} \cot \left( \frac{x}{2} \right) \quad (8.11)
\]

**Guidelines for Two- and Three-wire methods**

The ASTME has prescribed guidelines for measuring the effective diameter of a screw thread using wire methods. The following points summarize this:
1. Care must be exercised to exert minimum force while holding the wires against the screw thread. Since a wire touches a minute area on each thread flank, de
formation of wire and thread will be sufficiently large to warrant some type of correction.

2. The wires should be accurately finished and hardened steel cylinders. The working surface should at least be 25 mm in length. The wires should be provided with a suitable means of suspension.

3. One set of wires should consist of three wires having the same diameter within 0.000025 mm. These wires should be measured between a flat contact and a hardened and accurately finished cylinder having a surface roughness not over 5 \( \mu \text{m} \).

4. If it becomes necessary to measure the effective diameter by means of wires other than the best size, the following size limitations should be followed:
   (a) The minimum size is limited to that which permits the wire to project above the crest of the thread.
   (b) The maximum size is limited to that which permits the wire to rest on the flanks of the thread just below the crest, and not ride on the crest of the thread.

5. The wires should be free to assume their positions in the thread grooves without any restraint (the practice of holding wires in position with elastic bands can introduce errors in the measurement).

### 8.8.4 Measurement of Pitch

Usually, a screw thread is generated by a single-point cutting tool, with the two basic parameters being angular velocity of the workpiece and linear velocity of the tool. The tool should advance exactly by an amount equal to the pitch for one complete rotation of the workpiece. Pitch errors are bound to crop up if this condition is not satisfied. Pitch errors may be classified into the following types:

**Progressive pitch error** This error occurs whenever the tool–work velocity ratio is incorrect but constant. Generally, it is caused by the pitch error in the lead screw of the machine. Figure 8.28 illustrates a progressive pitch error, in which the cumulative pitch error increases linearly along the thread numbers. Other factors contributing to the pitch error are an incorrect gear train or an approximate gear train when, for example, metric threads are being generated on basically a system suited for producing British Standard threads.

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**Fig. 8.28** Progressive pitch error

**Fig. 8.29** Periodic pitch error