being 10 minutes of arc. In addition to micrometer readout, electronic readouts are available that operate by photoelectrically sensing the motion of the image of the reticle. In this manner, higher sensitivity and repeatability are realized.

The autocollimator can be used to measure the angle between two surfaces by placing the mirror in contact with the first surface, and then moving it to contact the second surface. The difference between the two readings is the angle between the two surfaces. This measurement is possible only if the two surfaces are adjacent to each other (within the size of the autocollimator apertures). If this angle is larger than the small range of the collimator, then an angular gage block may be added between the mirror and measured surface to bring the image within the operating range.

An autocollimator is capable of measuring right angles to a high order of accuracy (±1/2 second), when used with an accessory right-angle reflector (pentaprism). The prism has the capability to bend the light beam precisely 90° and is thus used as the standard for comparison when checking orthogonal surfaces.

Laser autocollimators are similar in concept to those described above, except that the coherent light source provides a high degree of collimation and brightness. Consequently, alignment may be made rapidly because the beam is visible in full daylight. Laser autocollimators are normally supplied with photoelectric readout for direct reading of angular displacement.

**SCREW THREAD GAGING AND MEASUREMENT**

Screw threads are important elements of mechanical design with wide and varied applications, particularly for controlled translational motion and for fasteners providing disengagable connections. The dimensional accuracy of screw threads is necessary to ensure the dependable assembly of threaded mating components, the interchangeability of the corresponding threaded parts, the consistent proportional relationship between the imparted rotational and resulting translational movements, and the mechanical strength of the threaded connection.

As is the case with all other mechanical elements, the actual sizes of screw threads on manufactured parts are not exactly identical to the pertinent design sizes. Such deviations may be within acceptable (tolerance) limits or exceed the applicable tolerances. Components with out-of-tolerance screw thread dimensions are considered defective products. For the threads to be acceptable, the dimensions of the different thread characteristics and elements must be held within specific limits. These limits are established in the standards for different thread systems and classes. Complete sets of standards are available for the commonly used thread systems such as unified, metric, acme, buttress, Whitworth, and pipe. Table 4-5 lists the standards available from the American National Standards Institute (ANSI) for these thread systems.

Although not everyone involved in thread measurement needs to become a thread expert, it is important to have a proper understanding of the nomenclature, specifications, and gaging principles to ensure the production and/or acceptance of dimensionally conforming threaded products. This section describes the different types of gages and instruments used in screw thread measurement, as well as the procedures for measuring the various parameters of product screw threads. For information on producing screw threads, refer to Volume I, Machining, of this Handbook series.

**THREAD NOMENCLATURE**

The terms commonly applied to screw threads may be classified in four general groups: (1) types of screw threads, (2) sizes and fits of mechanical parts in general, (3) geometrical elements of both straight and taper screws, and (4) dimensions of screw threads. The following definitions are limited to those directly associated with the gaging and measurement of screw threads. A more complete listing is contained in ANSI Standard B1.7. The terms relating to screw threads are shown in Figs. 4-71, 4-72, 4-73, 4-74, and 4-75.

**Terms Relating to Types of Screw Threads**

- **Classes of threads** Threads of a given type are distinguished from each other by the amounts of tolerance or tolerance and allowance specified. Various combinations of these tolerances and allowances have been set in tables to form a set of standard classes.
- **External thread** A thread on a cylindrical or conical exterior surface (see Fig. 4-71).
internal thread  A thread on a cylindrical or conical interior surface (see Fig. 4-71).

multiple-start thread  A thread in which the lead is an integral multiple, other than one, of the pitch.

screw thread  A screw thread is a ridge, usually of uniform section, and is produced by forming a groove in the form of a helix on the external or internal surface of a cylinder, or in the form of a conical spiral on the external or internal surface of a cone or frustum of a cone. A screw thread formed on a cylinder is known as a straight or parallel thread, to distinguish it from a taper screw thread that is formed on a cone or frustum of a cone.

single-start thread  A thread having the lead equal to the pitch.

Terms Relating to Size and Fit of Mechanical Parts

allowance  The prescribed difference between the design size and the basic size of a thread.

fit  The general term used to signify the range of tightness or looseness that results from application of a specific combination of allowances and tolerances in mating parts.

limits of size  The applicable maximum and minimum sizes.

maximum material condition (MMC)  The condition where a feature of size contains the maximum amount of material within the stated limits of size. For example, the minimum internal thread size and the maximum external thread size (see Fig. 4-72).

TABLE 4-5
Screw Thread Specifications

<table>
<thead>
<tr>
<th>Standard</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSI B1.1</td>
<td>Unified Inch Screw Threads (UN and UNR Thread Form)</td>
</tr>
<tr>
<td>ANSI B1.3</td>
<td>Screw Thread Gaging Systems for Dimensional Acceptability</td>
</tr>
<tr>
<td>ANSI B1.1a</td>
<td>Unified Inch Screw Threads (UN and UNR Thread Form)</td>
</tr>
<tr>
<td>ANSI/ASME B1.2</td>
<td>Gages and Gaging for Unified Inch Screw Threads</td>
</tr>
<tr>
<td>ANSI B1.12</td>
<td>Class 5 Interference-Fit Thread</td>
</tr>
<tr>
<td>ANSI/ASME B1.13M</td>
<td>Metric Screw Threads—M Profile</td>
</tr>
<tr>
<td>ANSI/ASME B1.16M</td>
<td>Gages and Gaging Practice for Metric M Screw Threads</td>
</tr>
<tr>
<td>ANSI B1.21M</td>
<td>Metric Screw Threads—MJ Profile</td>
</tr>
<tr>
<td>ANSI B1.22</td>
<td>Gages and Gaging Practice for “MJ” Series Metric Screw Threads</td>
</tr>
<tr>
<td>ANSI B1.5</td>
<td>Acme Screw Threads</td>
</tr>
<tr>
<td>ANSI B1.8</td>
<td>Stub Acme Screw Threads</td>
</tr>
<tr>
<td>ANSI B1.9</td>
<td>Buttress Inch Screw Threads</td>
</tr>
<tr>
<td>ANSI/ASME B1.20.1</td>
<td>Pipe Threads, General Purpose (Inch)</td>
</tr>
<tr>
<td>ANSI B1.20.5</td>
<td>Dryseal Pipe Threads (Inch), Gaging for</td>
</tr>
</tbody>
</table>

minimum material condition (least material condition, LMC)

The condition where a feature of size contains the least amount of material within the stated limits of size. For example, the maximum internal thread size and the minimum external thread size.

tolerance  The total amount that a specific dimension is permitted to vary. The tolerance is the difference between the maximum and minimum limits of size.

Terms Relating to Geometrical Elements of Screw Threads

axis of thread  The axis of a thread is coincident with the axis of its pitch cylinder or cone.

basic form of thread  The permanent reference profile from which the design forms for both external and internal threads are developed.

crest  The surface of the thread that joins the flanks of the thread and is farthest from the cylinder or cone from which the thread projects (see Fig. 4-7). The crest of an external thread is at its major diameter while the crest of an internal thread is at its minor diameter.

flank  The flank (or side) of a thread is either surface connecting the crest with the root. The flank-surface intersection with an axial plane is theoretically a straight line.

following flank  The following (trailing) flank of a thread is the one that is opposite to the leading flank.

form of thread  The form of a thread is its profile in an axial plane for a length of one pitch of the complete thread.

leading flank  The flank that, when the thread is about to be assembled with a mating thread, faces the mating thread.

load flank  The flank that takes the externally applied axial load in an assembly. The term is used in relation to unified, buttress, square, trapezoidal acme, and stub acme threads.

root  The surface of the thread that joins the flanks of adjacent thread forms and is immediately adjacent to the cylinder or cone from which the thread projects (see Fig. 4-7). The root of an external thread is at its minor diameter, while the root of an internal thread is at its major diameter.

Fig. 4-71  Screw thread terms relating to types and dimensions (single-start thread; lead equal to pitch).
Fig. 4-72 Maximum and minimum material limit profiles for: (a) internal threads and (b) external threads.

Terms Relating to Dimensions of Screw Threads

**addendum** The addendum of an external thread is the radial distance between the major and pitch cylinders or cones, respectively. The addendum of an internal thread is the radial distance between the minor and pitch cylinders or cones, respectively (see Fig. 4-73).

**crest truncation** The crest truncation of a thread is the radial distance between the sharp crest (crest apex) and the cylinder or cone that would bound the crest (see Fig. 4-73).

**dedendum** The dedendum of an external thread is the radial distance between the pitch and minor cylinders or cones, respectively. The dedendum of an internal thread is the radial distance between the major and pitch cylinders or cones, respectively (see Fig. 4-73).

**flank angle** The flank angles are the angles between the individual flanks and the perpendicular to the axis of the thread, measured in an axial plane. A flank angle of a symmetrical thread is commonly termed the half angle of thread.

**functional (virtual) diameter** The functional diameter (virtual condition per ANSI Y14.5M) of an external or internal thread is the pitch diameter of the enveloping thread of perfect pitch, lead, and flank angles, having full depth of engagement but clear at crests and roots and of a specified length engagement. It may be derived by adding to the pitch diameter in the case of an external thread, or subtracting
from the pitch diameter in the case of an internal thread, the cumulative effects of deviations from specified profile, including variations in lead (uniformity of helix) and flank angle over a specified length of engagement. The effects of taper, out-of-roundness, and surface defects may be positive or negative on either external or internal threads. A perfect internal or external GO-thread gage having a pitch diameter equal to that of the specified material limit and having clearance at crest and root is the enveloping thread corresponding to that limit.

height of thread The height (or depth) of thread is the distance measured radially between the major and minor cylinders or cones, respectively.

helix angle On a straight thread, the helix angle is the angle made by the helix of the thread and its relation to the thread axis. On a taper thread, the helix angle at a given axial position is the angle made by the conical spiral of the thread with the axis of the thread. The helix angle is the complement of the lead angle.

included angle The included angle of a thread (or angle of thread) is the angle between the flanks of the thread measured in an axial plane (refer to Fig. 4-71).

lead When a thread part is rotated about its axis with respect to a fixed mating thread, the lead is the axial distance moved by the part in relation to the amount of angular rotation. The basic lead is commonly specified as the distance to be moved in one complete rotation. It is necessary to distinguish measurement of lead from measurements of pitch, as uniformity of pitch measurements do not ensure uniformity of lead (see Fig. 4-74, view b). Variations in either lead or pitch cause the functional diameter of thread to differ from the pitch diameter.

lead angle On a straight thread, the lead angle is the angle made by the helix of the thread at the pitch line with a plane perpendicular to the axis. On a taper thread, the lead angle at a given axial position is the angle made by the conical spiral of the thread, with the plane perpendicular to the axis, at the pitch line.

major diameter On a straight thread, the major diameter is that of the major cylinder. On a taper thread, the major diameter at a given position on the thread axis is that of the major cone at that position (refer to Fig. 4-71).

minor diameter On a straight thread, the minor diameter is that of the minor cylinder. On a taper thread, the minor diameter at a given position on the thread axis is that of the minor cone at that position (refer to Fig. 4-71).

pitch The pitch of a thread having uniform spacing is the distance, measured parallel to its axis, between corresponding points on adjacent thread forms in the same axial plane and on the same side of the axis. Pitch is equal to the lead divided by the number of thread starts (see Fig. 4-74, view a).

pitch cylinder The pitch cylinder is one of such diameter and location of its axis that its surface would pass through a straight thread in such a manner as to make the widths of the thread ridge and the thread groove equal. On a theoretically perfect thread, the widths of each thread ridge and groove are equal to one-half the basic pitch (see Fig. 4-75).

pitch diameter On a straight thread, the pitch diameter is the diameter of the pitch cylinder. On a taper thread, the pitch diameter at a given position on the thread axis is the diameter of the pitch cone at that position. Note that when the crest of a thread is truncated beyond the pitch line, the pitch diameter, pitch cylinder, or pitch cone would be based on a theoretical extension of the thread flanks to a sharp vee at the major and minor diameters.

root truncation The root truncation of a thread is the radial distance between the sharp root (root apex) and the cylinder or cone that would bound the root (refer to Fig. 4-73).

threads per inch The number of threads per inch is the reciprocal of the pitch in inches.

MEASURING EQUIPMENT

A variety of thread gages and gaging equipment is currently being used by industry for the measurement of product screw
threads. The type of gage or equipment used depends primarily on the thread characteristics being measured and the accuracy required. Some of the commonly used gages are micrometers, fixed-limit gages, and indicating gages. Optical comparators, toolmakers' microscopes, lead testers, and helical-path analyzers are also used and are discussed in greater detail in Chapter 3, "Inspection Equipment and Techniques," of this volume.

**Screw Thread Micrometers**

Screw thread micrometers have a specially designed spindle and anvil so that externally threaded products can be measured. The end of the spindle of this type of micrometer is pointed to form a 60° cone, and the anvil has the form of a vee to fit over the thread (see Fig. 4-76). The sharp tip of the spindle is ground off to make sure that only the pitch diameter is measured rather than the root or minor diameter.

Flats are ground on the peaks of the vee, and the root of the vee is ground out. The anvil can be fixed in the frame or it can be free to rotate, permitting the anvil to adjust to the helix of the thread being measured. Specially designed anvils and spindles are also available for Whitworth and metric threads.

Screw thread micrometers for measuring American National and unified screw threads are available in sizes ranging from 1 to 6" in 1" increments. Micrometers for metric threads are available in sizes 0-25 mm and 25-50 mm.

A screw thread micrometer is generally designed to measure threads within a narrow range of pitches. To cover the whole range of pitches, several micrometers are required. One type of screw thread micrometer has replaceable anvils permitting the micrometer to measure the pitch diameter on the whole range of pitches.

**Fixed-Limit Gages**

Fixed-limit gages are single-purpose gages in that they are made for a specific thread system, form, size, and class. These gages incorporate the essential functional dimensions of the thread and are used primarily to ensure the ability to assemble the product thread with its mating part.

Fixed-limit gages are generally made from tool steel that has been treated for wear resistance and dimensional stability. For extreme part tolerances or abrasive work conditions, other gage materials, such as carbides and chrome plate, are used. Because solid thread gages are subject to wear, a periodic inspection of these gages should be made; worn gages should be discarded.

The accuracy to which these gages are manufactured is determined by their intended use. Gages that directly check the product thread are made to X tolerances. Gages that are used as reference or master gages are made to W tolerances. The X tolerances are two times larger than W tolerances. The designated tolerances for unified inch screw threads and metric screw threads are given in ANSI B1.2 and ANSI B1.16M, respectively.

The commonly used fixed-limit gages are thread plug gages and adjustable thread ring gages. Thread snap gages can also be classified as fixed-limit gages although some are adjustable.

**Thread plug gages.** Working thread plug gages are similar in design to cylindrical plug gages except that they are threaded. They are designed to check internally threaded products. The types of thread systems for which thread plug gages are available include unified, American National, metric, Whitworth, acme, buttress, and pipe. When thread plug gages are manufactured to W tolerances, they are used as reference or master gages for setting adjustable thread ring gages, thread snap gages, and indicating gages.

A typical thread plug gage consists of a handle and one or two thread gaging members (see Fig. 4-77). Depending on the gaging member size, the member can be held in the handle using a threaded collet and bushing design (view a), a taperlock design (view b), or by a trilock design (view c). The threaded collet and bushing design is generally used for gaging members ranging from 0.030 to 0.760" (0.76 to 19.30 mm); the taperlock design for members from 0.029 to 1.510" (1.50 to 38.35 mm); and the trilock design for members from 0.760 to 8.010" (19.30 to 203.45 mm). An annular design is used for gaging members above 8.010" (203.45 mm).

The two members in a thread plug gage are referred to as the GO and NOT-GO members. The NOT-GO member is sometimes referred to as the HI member. The GO gaging member is generally larger than the NOT-GO member and is used to check the maximum material functional limit of the product thread. The NOT-GO member checks the NOT-GO (HI) functional diameter limit of the threaded product.

**Thread ring gages.** Thread ring gages are similar in design to cylindrical ring gages except that the internal surface is threaded. They are available in both solid and adjustable or split designs. Minor adjustments of an adjustable thread ring...
gage can, at times, be made by qualified shop or inspection personnel. If the user is unsure of the correct procedure and/or does not have the proper truncated setting plug, the ring should be sent to a calibration or gage house for the adjustment.

Thread ring gages are supplied in pairs as GO and NOT-GO gages. The NOT-GO ring is sometimes referred to as a LO ring gage. The GO gage checks the maximum material functional limit of the threaded part. The NOT-GO gage checks the NOT-GO (LO) functional diameter limit of the threaded part and usually has an annular groove machined on the periphery of the ring to differentiate it from the GO ring.

**Thread Snap Gages**

Thread snap gages have two pair of gaging elements combined in one gage. With proper gaging elements, these gages can check the maximum and minimum material limit of external product screw threads in a single pass. One style of thread snap gage is shown in Fig. 4-78.

The functional or GO portion of the gage may incorporate either functional segments or functional rolls. Rolls rotate when the part is inserted, thus reducing wear. The length of the segments or rolls is approximately equal to the applicational length of engagement of the product thread. The NOT-GO portion of the gage generally contains cone and vee profile rolls.

Snap gages may be held on a stand where the threaded product is presented to the gage, or they can be used as a handheld gage by presenting the gage to the part that may be between centers in a machine. Snap gages are available in sizes from 0.060 to 20" (1.5 to 500 mm). In most cases snap gages are dedicated to one size or varying classes of a size. In addition, the same gage can be used for checking right and left-hand threads of the same nominal size.

**Indicating Thread Gages**

Several different designs of indicating thread gages are available for either internal or external screw thread measurement. Indicating thread gages must be set to the proper thread setting using master thread plug or thread ring gages before checking the threaded parts. Indicating thread gages for internal threads are made in sizes for measuring threads from 0.138 to 40" (3.5 to 1000 mm) diam and for external threads in sizes from 0.06 to 20" (1.5 to 500 mm) diam. A typical gage consists of a frame, a set of contact elements, and a dial indicator (see Fig. 4-79).

Contact elements are available for the commonly used thread systems and are identified by their nominal size and the number of threads per inch. Most indicating thread gages have either three contact elements spaced at 120° or two contact elements at 180°. Generally one, two, or three of the elements are movable to permit the threaded product to be inserted in the gage. The movable contact(s) is also connected to the dial indicator, which indicates the amount of deviation from a specified standard.

The contact element design determines the thread characteristics and elements that can be measured with a given gage. Because the elements are removable, one gage can be used for the measurement of a variety of thread characteristics, elements, and sizes.

Cone and vee segments or rolls that have thread pitch engagement at the pitch diameter line are used when measuring pitch diameter (minimum material size and limit). They can also be used to measure roundness and taper of the threaded product. Full-form segments or functional rolls can be used to measure the GO functional limit and size as well as roundness. When cone and vee contact elements are used in conjunction with full-form elements, the amount of variation of each individual thread characteristic and element can be determined. This procedure is commonly referred to as differential gaging. The position of the minor (internal threads) or major (external threads) diameter with respect to the pitch diameter, referred to as runout or eccentricity, can also be measured with a combination of plain and threaded contact elements.

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![Fig. 4-78 Thread snap gage with functional segments and cone and vee profile rolls. (The Johnson Gage Co.)](image1)

![Fig. 4-79 Indicating thread gage with full-form segments. (The Johnson Gage Co.)](image2)
CHAPTER 4

SCREW THREAD GAGING AND MEASUREMENT

MEASURING METHODS

One of the basic fundamentals of thread gaging is to select gaging that is as consistent as possible with the requirements of the application and threading process. The proper gage selection ensures the highest degree of repeatability and reduces the probability of generating sort, scrap, rework, and selective assembly conditions.

The two primary categories of screw thread inspection are inspection by attributes and inspection by variables. Inspection by attributes involves the use of fixed-limit gages (thread plug, ring, and snap gages) and only provides for a limit check of the functional size (maximum material). Inspection by variables involves the use of comparative type instruments or gages (indicating thread gages, micrometers, precision measuring machines along with wires, optical comparator, and lead tester) to determine the extent of deviations of product threads and their individual elements in addition to determining size relative to maximum and minimum material limits.

Before measuring the threaded screw product to determine if it is dimensionally acceptable, it is advisable to visually inspect the screw threads using a magnifying glass. Some of the items to look for are dirt, chips, splinters, malformed threads, or a drunken helix. If these items are present and a fixed-limit gage is used, undue wear will occur resulting in a reduction of gage life. It is also advisable to check the thread count or pitch measurement using a rule or screw-pitch gage.

Method Selection

In the past there has been confusion over the acceptability of product screw threads. Much of the confusion has been due to the means by which federal and commercial standards have defined thread acceptability. In earlier standards, thread acceptability was based on the type of gage used for inspection rather than the actual dimensions. Recently, ANSI has developed Standard B1.3, "Screw Thread Gaging Systems for Dimensional Acceptability." This presents screw thread gages and measuring equipment suitable for determining the acceptability of UN, UNR, and UNJ screw threads on externally and internally threaded products. It also establishes the criteria for screw thread acceptance when a specified gaging system is used.

Unfortunately thread standards define the maximum material functional limit (virtual condition) geometry and then allow deviations. However, the geometry of the minimum material condition is of greatest concern to the designer because failure is most likely to occur if perfect form is not assessed.

Tables 4-6 and 4-7 (see pages 4-42 and 4-44) list the gages, gaging elements, and measuring equipment that can be used in the measurement of screw threads on external and internal products, respectively. The horizontal column contains the various screw thread dimensions and the vertical column contains the gages or equipment currently being used to gage or measure product screw thread dimensions. The horizontal column is also subdivided, where appropriate, into functional limit and size columns. Functional limit refers to attributes inspection and is a qualitative assessment, which only determines if a characteristic is in conformance. Functional size refers to variables inspection and is a quantitative and qualitative assessment. The assessment is then compared with tabled values to determine if the characteristic is in conformance. The type of gage or measuring equipment that could be used to determine a specific screw thread characteristic is designated by a black dot in the body of the appropriate table.

Three levels (systems) of dimensional conformance for external and internal product screw threads are identified in ANSI B1.3 as System 21, System 22, and System 23. The difference between these systems is the level of inspection required to determine dimensional conformance. Although these three levels of dimensional conformance exist, different gages or measuring equipment are not always required for each level.

System 21 provides for interchangeable assembly with functional size control at the maximum material limits within the length of standard gaging elements. It also controls the characteristics identified as HI (internal) and LO (external) functional diameters.

System 22 provides for interchangeable assembly with functional size control at the maximum material limits within the length of standard gaging elements and also control of the minimum material size limits over the length of the full thread. Other thread characteristics such as lead, flank angle, taper, and roundness variations are confined within these material limits; however, control of their magnitude is not specified.

System 23 provides for interchangeable assembly with functional size control at the maximum material limits within the length of standard gaging elements. It also controls the minimum material size limits over the length of the full thread. The magnitude of the other thread characteristics such as lead, flank angle, taper, and roundness are further controlled within these limits.

The screw thread of a threaded product is considered acceptable when each of the thread characteristics specified in the designated gaging system are found acceptable. The gaging system used to inspect the screw thread product per ANSI B1.3 must be specified in addition to thread size designation and thread class in the product standard, procurement drawing, or purchase inquiry and order. Thread acceptability requirements may be specified by a general note on the drawing or procurement document or by showing the system number (21, 22, or 23) in parentheses following the thread tolerance class designation.

Tables 4-8 and 4-9 (see pages 4-46 and 4-47) list the dimensions that must be inspected to determine thread acceptability by the different gaging systems along with the gages and gaging equipment that can be used. The numbers in the attributes and variables columns correspond to the numbers in the thread gages and measuring equipment column of Tables 4-6 and 4-7. Gages and gaging equipment are manufactured for various thread types, sizes, and classes.

Micrometer Measurements

A screw thread micrometer with modified pitch line contacts can be used to measure the minimum material pitch diameter limit and size of an external screw thread. The screw thread micrometer can also be used to check roundness and taper of the pitch cylinder.

The zero setting of a screw thread micrometer capable of measuring 0-1" or 0-25 mm is achieved by establishing direct contact between the spindle cone and anvil vee. A checking standard is usually supplied for larger capacity micrometers. The pitch diameter is represented by the reading on the micrometer sleeve and thimble when the spindle cone and anvil vee are in contact with the thread.

When measuring the pitch diameter of threaded products with a screw thread micrometer, small errors in measurement are sometimes introduced. The errors often result from a slight variation of the anvil position on the thread because the anvil is used to measure a range of pitches. To compensate for this
error, it is recommended that the pitch diameter of a known standard plug gage be measured and the difference noted. The difference between the measured value and the known value should then be added or subtracted from the values obtained for the threaded products.

**Measurement Over Wires**

The pitch diameter of an externally threaded product can be measured using accurately finished and hardened steel wires along with a suitable measuring device. Generally, three wires are used, but two wires are used when measuring the pitch diameter of taper pipe threads. Measuring the pitch diameter over wires is commonly used in checking the accuracy of threaded plug gages and other precision screw threads. It is normally used to check parts in ordinary manufacturing practice because thread gages require less time and are preferable for shop measurements. The pitch diameter of internal screw threads can also be measured. For this application, three balls are used instead of wires as contact elements along with a measuring machine that has special ball-holding gaging arms.

When measuring screw threads by the three-wire method, two of the wires are placed in the thread groove on one side and one wire is diametrically opposed (see Fig. 4-80). The measurement over the wires is then made using a micrometer or other length measuring instrument. The accuracy of the pitch diameter measurement depends on the measuring instrument, the wire diameter, and the contact force.

To measure the pitch diameter of a threaded product to an accuracy of 0.0001" (0.003 mm) requires strict adherence to the following:

- The best-sized wires shall comply with the specifications listed for wires in ANSI B1.2.
- The diameter of the wires must be known to within 0.00005 (0.0005 mm).
- The measurement over the wires should be made with a measuring instrument that has flat, parallel contacts and reads directly to 0.00001" (0.0003 mm).
- The measuring instrument should have a means for directly adjusting the measuring or contact force for the various values specified.
- The wires should be free to assume their positions in the thread grooves without restraint. Holding wires in position with elastic bands can introduce error.

- The measured value should be given to five decimal places to ensure accurate values for pitch diameter measurement.
- Measurements should be made at 68°F (20°C).

**Wire size.** A set of wires consists of three wires having a hardness equivalent to a Knoop indentation number of 630 and a surface finish better than 2 μm (50 μm) arithmetic average. The best size of wire to use is the diameter that will contact the thread flanks at the pitch line. The best-sized wire is used because the measurements of pitch diameter are least affected by errors that may be present in the flank angle of the thread. The best-sized wire for most types of screw threads, assuming lead angle does not exceed 5°, can be approximated using the equation:

\[ w = 0.5p \times \sec \alpha \]  

where:

- \( w \) = diameter of wire, in. (mm)
- \( p \) = pitch of the thread, in. (mm)
- \( \alpha \) = one half of the included angle of the thread, deg

For threads with a 60° included angle (unified and metric), Eq. (5) becomes:

\[ w = 0.57735p \]  

For threads with a 29° included angle (American National buttress threads, ANSI B1.9) can be approximated using the equation:

\[ w = 0.54147p \]

If it becomes necessary to measure the pitch diameter with wires other than the best size, the following limitations should be adhered to:

- The minimum wire size is limited to the diameter that permits the wire to project above the crest of the thread. Care should be taken that the wire does not bottom out on the root of the thread and give an erroneous reading.
- The maximum wire size is limited to the diameter that permits the wire to rest on the flanks of the thread just below the crest.

The diameters of the best-sized, maximum, and minimum wires for unified threads are given in Table 4-10 (see page 4-48).

**Measuring force.** When measuring the pitch diameter of screw threads or screw thread gages by the three-wire method, variations in contact force will result in different measurement readings. The force used should be sufficient to align the wires in the thread grooves or gage without deforming the wire or threads. In general, the measuring force is dependent on the thread type and pitch as given in Table 4-11 (see page 4-48).

**Pitch diameter equations.** The equations in Table 4-12 (see page 4-49) can be used for computing the pitch diameter from the measurement over wires of different types of screw threads having lead angles from 0 to 5°. It is important to note that these equations neglect the effect of lead angle, thereby giving results that are slightly larger than the true condition. If the lead angles are large enough to decidedly affect the result, as in the case of multiple threads, an equation that compensates for lead angle should be used.\(^\text{22, 23}\)

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*Fig. 4-80 Measuring the pitch diameter of an external thread using the three-wire method. (The Van Keuren Co.)*