## ECONOMICAL CHOICE OF BORE GAGE DEPENDS UPON YOUR APPLICATION

Indicating bore gages come in two basic varieties: adjustable-capacity gages with interchangeable contacts or extensions; and fixed-size gages with plug-type bodies. While indicating plug gages can measure closer tolerances with higher repeatability than adjustable ones, these are only two of several factors to consider when selecting a bore gage. A wrong decision can mean unnecessary expense, low throughput, and even inaccurate date.

There is still a place in many shops for adjustable bore gages. Where tolerances are medium to broad, or production runs are low or involve many different bore sizes to be measured, adjustable gages can be a bargain. Their range is typically two to three times greater than that of plug gages (0.010” vs. 0.003” - 0.006”), so they are more practical to use with broader tolerances. Because an adjustable gage can measure a range of hole sizes, some shops can get away with just three units, with capacities of 0.500” - 1.00”, 1.00” - 2.00”, and 2.00” - 8.00”. With indicating plug gages, on the other hand, a separate size plug is required for every different bore size to be measured.

The two types of gages are comparable in price (generally $400 - $600), but for a broad-tolerance operation, the smaller number of adjustable gages required will create a substantial savings. When you figure in the cost of masters, the savings can be multiplied.

For large-ID applications, adjustable bore gages are again the economical choice. Over about 4.5 inches, most plug-type gages are “specials” and, consequently, expensive (likewise for masters). Adjustable gages and masters are available from stock with capacities up to 24 inches.

The greatest benefit of fixed-size plug gages is the elimination of “rocking” to center the gage in the bore. The self-centering plug gage virtually eliminates operator influences and required very little training. Rocking an adjustable gage is a refined skill that must be learned and performed conscientiously (Figure 1 and 2). A poorly-trained operator, or one who is tired or hurried, is likely to produce incorrect measurements. Adjustable gages are also more subject to intentional operator influences, also known as the “close-enough syndrome.”

*Fig. 1—Positive Centralization. Centralizing contacts locate the measuring contacts centrally on the hole diameter.*

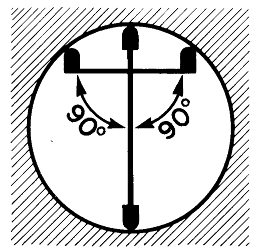
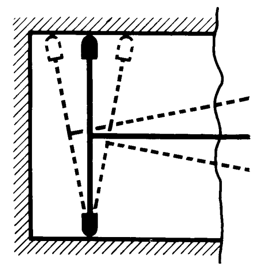



*Fig. 2—Positive Perpendicular Location. Rocking gage slightly locates contacts squarely across hole as indicated by MINIMUM reading on indicator.*



The elimination of rocking speeds measurement-taking considerably. Mastering is likewise simplified and accelerated. In any production run where volumes are high and/or tolerances are tight, plug gages create time savings that quickly amortize their higher purchase price.

I am not endorsing indicating plug gages over adjustable ones, but the fact is, they offer more benefits overall. Plug gages have larger bearing surfaces which make them less subject to wear. They are capable of better repeatability and discrimination. And they are the only logical choice for use with an electronic data collection system. It is nearly impossible to hold and adjustable gage steady on the true diameter of the bore, and at the same time, push a button to record the reading.

To summarize: Use adjustable bore gages where production runs are low and/or tolerances are medium to broad. Use self-centering plug-type gages where quantities are high and/or tolerances are medium to tight.

## MEASURING DEEP HOLES

Measuring IDs of "deep holes" involves a few special considerations. Deep is relative, but we'll define it here as being anywhere from roughly eight inches to 30 feet. Although the equipment and the methodology stay basically the same as for shallower holes, depth can influence accuracy, choice of gage type, and speed of operation.

The most basic deep bore gage is the mechanical, rocking-type gage, which comes in two basic flavors: self-centralizing, and non-centralizing. The self-centralizing type is easier to use, because it requires rocking in only one plane. It offers high resolution (typically .0001"), but has very restricted range (typically .025" or less). The fixed contacts on the centering mechanism offset the gage head from the bore's centerline. In narrow deep holes this restricts the ability to rock the gage, which can interfere with some measurements.

The non-centralizing gage has no fixed contacts: it has two or three sensitive contacts that retract with a trigger mechanism. It requires a bit more skill to use, and has relatively limited resolution (typically .0005"), but a long measurement range (up to 1-3/8"). Ironically, the head of the non-centralizing gage is automatically centered, which permits rocking to a greater extent.

Both types are available off the shelf for use at depths to about 12", but can be made to go deeper with the use of mechanical extensions. We've seen as many as six four-foot extensions screwed end to end to check for wear on the screw barrels of injection molding machines. However, because of the limitations of long mechanical transfer, it's difficult to obtain accuracy greater than about .0005" in this kind of situation.

Mechanical plug gages are self-aligning, which reduces the error potential of rocking-type gages and speeds gaging throughput. When used in conjunction with dial indicators, mechanical plug gages are subject to the same limitations of long-motion transfer as rocking-type gages. But it is possible to mount an LVDT right on the plug and feed them down the hole together on the end of a long rod. The signal from the LVDT runs over a wire to an amplifier on the "surface." In this way, mechanical measurements with resolution of .000050" are possible for the deepest holes.

Rocking-type gages are limited to IDs of roughly 1" or greater in deep-hole applications, while mechanical plug gages allow ID measurements down to about .200". To get smaller than that, you have to eliminate moving parts altogether and go to air gaging. With special hypodermic tubing, air gaging can measure down to .100".

Air is also practical for large IDs. It is often difficult to thoroughly clean a deep hole, and air gaging is very forgiving of dirt, oil, and other contaminants, both in terms of accuracy, and in terms of maintenance and longevity of the gage. This is especially important when gaging IDs of oil well pump barrels, which are some 30' long and about as dirty as anything you'd ever want to gage.

Air's non-contact aspect provides other benefits. It is common practice to measure IDs at two-foot intervals along the length of these pump barrels. Mechanical gage contacts would be subject to a great deal of wear under these conditions, but the jets on an air gage are unaffected. In another example, when measuring IDs of nuclear fuel rods, a non-contact gage is essential to avoid burnishing interior surfaces.

Because air gaging is, in a sense, the "standard" for deep holes, it's worth noting a few application tips:

- The deeper the hole, the longer air pressure takes to stabilize. In the case of an oil well pump barrel, this can mean 10-15 seconds.

- Air gages are calibrated for use within certain ranges of atmospheric pressure. If a gage is to be used at widely different heights above sea level (common for some oil-field users), it will be necessary to recalibrate it. This is easily done by checking a lookup table from the manufacturer.

- Special dial faces make some jobs easier. The oil industry, for example, commonly uses a face with +.008" to the left of Zero, and just -.002" to the right of it. This is because they are only checking for oversize caused by wear. Most gage makers will gladly design dials for special applications.

- Air plugs are available in a wide range of standard styles and specials. For gaging blind holes and counterbores, reverse venting is machined into the plug to allow air to escape. Blind- and super-blind plugs with very short lead-in sections are available for measuring to within .085" of the bottom of blind holes. Plugs may have pins inserted or dogs machined in to align the jets with specific workpiece features (e.g., for checking groove and land diameters on rifled gun barrels). Jets may also be arranged to permit measurement of TIR (total indicated reading) conditions and straightness as well as IDs.

In most instances, deep holes are just like shallow ones -- only deeper. Measuring them is not a deep subject: it just requires a bit more care to select the right tool for the job.

## LONG RANGE BORE GAGES

Long range bore gages offer users a great deal of versatility. These rocking-type gages without fixed centralizing contacts offer measurement ranges as "short" as 1/8" (3mm) and as long as 1 3/8" (35mm). With replaceable contacts of varying lengths and shapes, their capacities are readily adjustable across a large span of nominal sizes: more than 2" (51mm) of adjustability is not uncommon. Taking both their long measurement range and their adjustability into account, it is possible to inspect IDs from 0.670" to 7.462" (17mm to 189.5mm) with just four gages.

Long range bore gages feature trigger mechanisms that retract the contact points, permitting the gages to be inserted with ease in bores of varying sizes. This feature also provides access to bores that are larger than the entry hole. The contacts are sprung strongly to the "out" position, so releasing the trigger puts the contacts firmly against the sides of the bore.

These gages are normally equipped with long range dial indicators that typically resolve to 0.0005" or 0.001" (0.01mm or 0.025mm). In comparison, rocking bore gages with centralizers may have either dial or digital indicators, and typically have a shorter measurement range of about 0.025" (0.39mm), but higher resolution of 0.0001" (0.002mm). Thus, the long range gages are more appropriate for use in low to medium-tolerance inspection tasks.

Common applications include: gaging IDs of rough castings or forgings; measuring features whose nominal dimension is unknown; and inspecting used parts that have been subject to substantial amounts of wear. For example, IDs of used oil field pump barrels as long as 70' can be inspected with the use of extension rods. Of course, long range bore gages can also be used for conventional inspection of medium-tolerance ID machining operations.

Many long range bore gages are available in both two- and three-contact versions, the latter having the contacts oriented at 120° to each other. The two-contact gages are particularly flexible, and may be used in non-ID applications to measure inside dimensions between two parallel surfaces: slot widths, for example. The three-contact versions, which can only measure circular features, are useful for inspecting bores for three-point out-of-roundness.

Long range bore gages must be centralized by "rocking" them in two directions. This is essential to ensure that the gage measures the bore's true diameter. First, the gage is rocked side to side, to center the contacts on the bore's axis. While rocking side to side, the user observes the indicator needle and watches for the maximum reading, indicating that the gage is not measuring a chord of the circle. Next, the gage is rocked up and down, to set the contacts perpendicular to the axis of the bore. In this case, the user watches for the minimum reading, indicating that the gage is not measuring a diagonal.

Non-centralizing bore gages require high levels of care and experience to obtain accurate results. A hurried approach will produce errors. The operator must have the patience to rock the gage several times in both directions while closely observing the indicator needle as it swings. Skill is also required to maintain the side to side centering while rocking the gage up and down. Long range bore gages with three contacts are somewhat easier to centralize than two-contact gages, but still must be rocked in both directions.

Other types of bore gages require less skill, and are quicker to use. But the long measurement range and adjustable capacity of non-centralized bore gages make them especially versatile, and consequently, potentially very economical where bores of many different nominal dimensions must be measured in small quantities.

## CHECKING BORES FOR OVALITY AND TAPER

Do you know the amount of ovality and taper of your bores? Are you sure you want to know? The decision can mean a big difference in the gage you select and the way you use it.

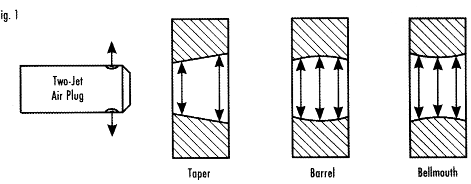
Checking ovality is primarily a job for air gaging, but there are exceptions: If you are interested in knowing whether a condition of ovality exists, but you don't need to actually measure it, then you might get by with an adjustable, rocking-type bore gage. Take one diameter measurement, then rotate the gage 90 degrees and take another. If the bore is oval, you will see a difference in the readings. But because you didn't necessarily hit the highest and the lowest points, you won't know how oval it is.

It is impractical to use a rocking-type gage to measure ovality, because it is virtually impossible to hold the gage in alignment while you rotate it through a full 180 degrees.

To measure ovality, you will want an air plug with two, and only two, jets, located 180 degrees apart. Take a measurement, then rotate the part (or the plug, depending on the setup) through a full 180 degrees, noting the maximum and minimum readings on the dial. (A two-contact, mechanical plug-type gage will also work for this application.)

If, on the other hand, you want to ignore ovality, select an air plug with four jets set 90 degrees apart. By the nature of air gaging, the four jets will average the readings between the minimum and maximum diameters. You won't even have to rotate the part on the plug. This is fine for some applications; for example, a press-fit bushing that conforms to the shaft when it is installed. In fact, it may be desirable for the purposes of process control to ignore the variations that would show up if one part were measured at its largest ID, the next part at its smallest, and the third one somewhere in between.

Fig. 1

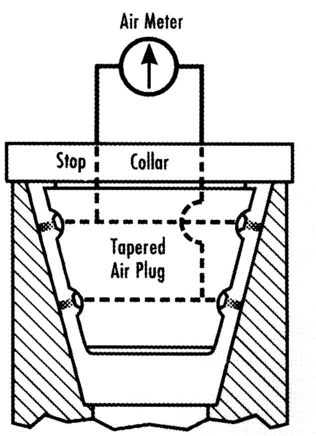



The above considers only simple ovality--essentially, a two-lobed condition. If you wish to measure lobing of greater frequencies, air plugs with as many as 12 jets can be used. Checking bores for undesirable taper is similar to checking ovality. (We will not discuss measuring intentionally-machined tapers.) Use a multiple-jet air plug to measure first near one end, and then near the other end of the bore, and simply note the difference, if any. If process analysis has indicated a need to check for barrel shape or bellmouth, take a measurement in the middle as well.

Of course, a four-jet plug will automatically ignore ovality, which may be desirable. If you wish to check ovality and taper in one operation, use a two-jet plug, measuring the bore at the bottom and the top, and rotating the workpiece or the plug at both ends. This method can get confusing, however, and you may prefer to do it in two separate operations.

Air gaging is a natural choice for measuring holes that are intended to be tapered (for example, Morse taper). This method of measuring taper is easy, fast and accurate, although it involves slightly more elaborate equipment. A plug with two separate air circuits is connected to the air gage so that each circuit acts on opposite sides of the precision diaphragm. Simply place the workpiece on the plug, and the gage will automatically indicate any variation in taper, based on the differential of air pressure between the two circuits.

Fig. 2




Air gaging makes quick work of measuring ovality and taper. When to select air gaging over mechanical gages for other applications is the subject of next month's column.

## MEASURING BLIND HOLES AND COUNTERBORES

Some time ago I wrote, that when measuring hole diameters, adjustable, "rocking"-type bore gages work well for broad tolerances and small production runs, while fixed, plug-type gaging is the practical choice for tight tolerances and high throughput. Plug-type gages automatically center themselves in the hole, eliminating the possibility of angular error in measurements. Let's now consider measuring blind holes and counterbores with plug-type gages. Both types of holes are gaged similarly, so for the sake of economy, I'll use the term "blind hole" throughout.

When machining blind holes, the front face of the tool does all the work, so it wears more quickly than through-hole tooling. Also, in any blind hole, a fillet occurs naturally in the angle between the "front" (i.e., bottom) and sides. As the tool wears, the fillet starts to inch up the sides, constricting the I.D. along the way.

It's easy enough to throw out bad parts when they occur, but a better reason to gage parts is to control the process, and avoid making rejects in the first place. In order to catch tool wear in time to control the process, special tools are needed for blind holes. Blind hole gages measure close to the front of a hole. How close? There are three types of blind hole gages.

| Gage type | Height |
| --- | --- |
| (standard) blind | .156" |
| super-blind | .08" |
| super-super-blind | .030" |

The height figure is the distance from the front of the plug to the centerline of the sensitive contact. (For comparison, the height-to-contact-centerline on a through-hole gage is 1/2" to 3/4".) The height specs, and the "blind/super/super-super" terminology are, believe it or not, industry standards.

Examine the part print to find the critical depth of the hole diameter, and choose the type of blind hole gage accordingly. Check especially if a precision mating part has to bottom out in the hole: an overly-tall fillet will cause unacceptable interference. "Super" and "super-super-blind" plugs are usually used in connection with shallow holes, while standard blind hole gages may be for holes of any depth. All three types are available in diameters ranging from .217" to about 14".

Blind hole gages are relatively susceptible to wear and damage. The plugs lack the tapered, lead-in sections of through-hole gages, so the measuring surface itself is used to line the gage up to the hole. In the process, these critical dimensions are subject to a lot of bumps and wear. And the sensitive contact, being much closer to the front, can be readily struck against the edge of the hole; this is a common source of damage.

The entire front end of a through-hole plug could, in theory, be worn away, and the back end would still center the gage in the hole. With a blind hole gage, there is no front end: centralization occurs only behind the sensitive contact. Wear, therefore, begins on the only available centralizing surface from day one. Because blind hole gages are more subject to wear and also less tolerant of it, one cannot expect them to have the longevity of through-hole gages. So don't use blind hole gages where through-hole gaging would work.

Although a blind master is recommended, many people use standard master rings to check blind hole gages. You can get away with this if you're careful. Make sure you master at the same depth you measure; otherwise, wear at the front of the gage body may be masked by better centralization further back. This could give you great repeatability on the master, and none in actual practice.

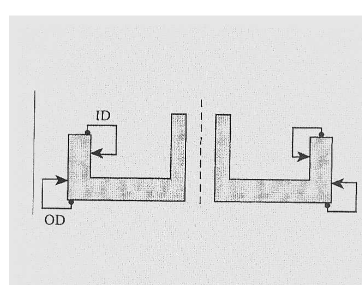
Also note that master rings are only certified at certain depths: there's no guarantee they're accurate near the top or bottom. Be especially wary of this with super-blind gages. Drop a few quarters in the ring to bring your gage up to the right height. The key to good mastering is to duplicate measuring conditions as closely as possible.

Through-holes tend to be self-cleaning, but blind holes need to be cleaned of chips and other debris before measuring. One can use coolant if the hole faces downward. Otherwise, compressed air is the best bet.

## A SHALLOW BORE (THIS IS NOT AN AUTOBIOGRAPHY)

Imagine a large rotor with an ID of 12". One normally uses an adjustable bore gage, or perhaps an inside rod micrometer, to check the diameter. But in this case, a hub in the center of the part presents an obstacle. For this type of measurement we need a special type of gage, called a shallow bore gage (sometimes called a shallow diameter gage or shallow ID/OD gage). These gages may be used where the diameter is reasonably close to the face surface of the part (usually 3" or less), and where the face surface is flat and square to the feature axis. While some of these gages can measure diameters as small as 2" or so, larger dimensions are more common, and gage capacity can range up to several feet.

A rail usually serves as the frame of a shallow bore gage. An anvil post, with a reference contact, extends perpendicularly from the bottom of the frame. The sensitive contact extends below the rail at the opposite end, for the final leg of the "C." The sensitive contact is connected via a low-friction linkage to an indicator on top of the rail. Depending upon the specific gage, either or both contacts may be adjustable along the rail, and both are adjustable for depth. (For gages offering more than 3" of depth capacity, special bracing or heavier contacts are required to provide the necessary rigidity.) The contacts are usually back-tapered, to ensure true point-to-point measurements. Rest feet are provided to establish a reference plane parallel to the measuring plane of the part. These, too, are adjustable linearly to accommodate different diameters.



Most gages offer about 6" of capacity adjustment. On some gages, rails of different lengths may be interchanged, so that the range of adjustment may be virtually unlimited. Frames can be configured to avoid interference with protruding features in the center of the part. With so many adjustments possible, shallow bore gages are adaptable to a wide range of applications, including grooves, tapers, cylinders, and features recessed behind blind shoulders.

Because the diameters being measured are usually large, dial indicators with resolution of 0.0001" or 0.0005" are typical. For applications requiring higher resolution or data output, higher resolution indicators, digital indicators, or even electronic transducers can be substituted. The electronic devices, with their ability to automatically capture the "min" or "max" value during the sweep, may also be preferred as a means of reducing operator errors. Some gages provide the option of mounting the indicator either horizontally or vertically, to improve visibility in some applications.

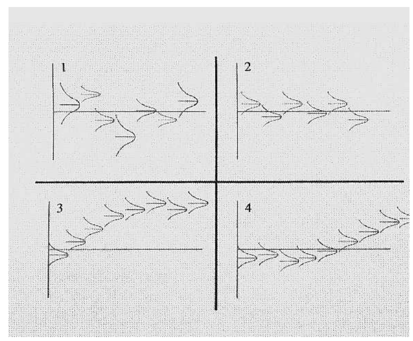
In use, the gage is swept across the diameter to find the maximum or minimum reading, depending on whether the feature is an ID or OD. Some gages include a centralizing device, which can be helpful but does not eliminate the need to "rock" the gage.

Mastering is usually done with adjustable setting masters, which must first be set to the nominal dimension with a gage block stack or end rods. Gaging depth is usually set by eye, placing a steel scale beside the contacts as they are screwed in or out. Where depth is critical (as with tapered features), the rest feet are placed on gage blocks of the appropriate height, and the contacts are adjusted up or down until they just touch the reference surface. If the bottoms of the contacts are radiused, make sure the gage block height is raised accordingly.

## ASSESSING GAGE STABILITY

When multiple part measurements show unacceptable variation, it is essential to understand whether it is the manufacturing process or the measuring process that is at fault. If inaccurate measurements are relied upon, one may make adjustments to a manufacturing process that is in reality accurate and under control.

Gage stability implies different things in different contexts. If taken literally, it may refer to whether there is something loose on the gage, or some other gage problem occurs randomly, to cause two identical trials to produce different results. When plotted on a histogram, this type of instability shows up as a distortion of the expected bell-curve shape—perhaps in the form of dual modes (i.e., high points) with a dip in between, or in a mode that is skewed toward one end of the tolerance range or the other.




Other types of stability are best assessed and visualized through the use of control charts, in which measurements of several small lots, each represented by a histogram, are compared over a period of time. A single, certified master or other qualified part should be used for the entire series of repeated trials. This serves to eliminate part-to-part error as a variable, so remaining variation will likely be low. Nevertheless, testing may show that variation between lots becomes significant enough over an extended period so as to constitute a measurement problem.

"Statistical stability" refers to the consistency of the measuring system's performance from lot to lot. If a gage is statistically stable, each lot or histogram will be nearly identical in shape and range (R), and the average value (X-bar) of subsequent lots will be close to one another. If it is statistically unstable, the histograms will vary in terms of their X-bar or R values, or both.

Figure 1 shows statistical instability of both sorts. The histograms vary considerably in their ranges and shapes, while the mean dimensions are clearly irregular from lot to lot.

"Long-term" and "short-term" stability are confusing, because both require a long-term effort to assess. Both describe trends in the X-bar or R values across multiple lots. If we were to draw a line connecting the X-bar value of each histogram in Figure 1, we would observe no clear trend. Thus, we cannot make a meaningful assessment of either long- or short-term stability.

In Figure 2, the R values are nearly identical, and the X-bar values are grouped much more closely, so the gage is statistically stable. A line connecting the X-bar values would show a clear trend along the nominal value, so we have good long-term stability. This chart shows realistically how the performance of a good, stable gage looks.

Figures 3 and 4 both show good statistical stability. But in Figure 3, there is a short-term stability problem, with a bias in the plus direction. After a few sets of trials, however, the measurements become stable and remain so over the long term. The problem may be due to a warm-up condition in the gage itself. Or it might be the result of contamination that has settled on the gage over night. The X-bar value shifts as the contaminant is dispersed, due to mechanical interaction between the gage and the samples being measured. After a few dozen trials, all the contaminant is dispersed and the measurements become stable.

Figure 4 illustrates the opposite situation. The gage is stable on startup and over the short term, but over the longer term it becomes unstable as the X-bar values begin to drift upward. This might be the result of external thermal influences. If performance were to be charted over a longer period, the X-bar values might drift back toward nominal again; this might indicate the gage is responding as the plant warms up in the morning, then cools down toward evening.

It is important to check gages for stability, in order to avoid making inappropriate adjustments to the manufacturing process. In some cases, solving the problem may be as simple as establishing a more frequent schedule for remastering the gage. In others, it could require a reevaluation of the entire gaging process.

## GAGING COUNTERSUNK AND CHAMFERED HOLES

While countersunk and chamfered holes are similar in appearance, functionally they are quite different. Consequently, different gages exist to serve these different functional requirements.

Hole chamfers are usually specified simply to make it easier to insert a screw, pin, bushing, or other assembly component. After the part is assembled, the chamfer typically serves no function. The component doesn't bear on the chamfer, so diameter and angle tolerances are usually not critical to the part's performance.

A countersink, on the other hand, is a functional surface upon which a fastener head bears. Because fastener performance is so important, countersink tolerances are critical. The countersinks on an aircraft's skin are an excellent example. If the countersink is too deep, there may be inadequate skin material for the rivet to hold against the underlying frame. If it is too shallow, the rivet head will protrude, increasing air resistance. This latter condition may sound trivial, until you consider the cumulative effect of literally hundreds of thousands of protruding rivet heads on an airplane's skin.

Countersinks tend to be small—usually 0.780" or less—and angles are closely controlled: usually 30°, 82°, 90°, 100°, or 130°. Chamfers may be specified at any angle up to 130°, and on holes or inside diameters of any size.

Both countersink gages and chamfer gages are usually hand-held instruments, although both can be mounted on bench stands, which is convenient if the parts being measured are small. They both perform the measurement by means of a plunger mechanism, but they do not measure the depth to which the angled surface extends into the hole. Rather, they measure the major diameter of the feature—that is, the largest diameter of the hole, where it intersects the top surface of the part. To convert the vertical motion of the plunger into a diameter measurement, the gages require an indicator with a special-ratio movement or readout.

The main difference between countersink and chamfer gages is the configuration of the plunger. Chamfer gages have an angled plunger consisting of three fluted sections. The angle of the plunger must be greater than the angle of the chamfer, to ensure that the plunger contacts the major diameter only. Typically, the range is split in two— from 0° to 90° and from 91° to 130°— so that two gages have traditionally been required to measure the entire range of chamfers. Recently, however, gages with replaceable plungers have been introduced (made possible by the introduction of electronic indicators with adjustable-ratio displays), allowing a single gage to be used with chamfers of any angle. Replaceable plungers also provide flexibility to measure across a larger range of diameters, and to switch between ID and OD chamfers.

Because countersinks are more critical, countersink gages have conical plungers that fit closely against the entire surface of the countersink feature. While some slight difference in the angles of the plunger and the countersink is acceptable, there must be a fairly close match between them. There are no replaceable-plunger countersink gages available at this time, so separate gages are required for each angle requiring inspection.

Both types of gages may be mastered against a part master that duplicates the specified chamfer or countersink. Chamfer gages can also be mastered against any certified flat surface. In most cases, this means the gage will perform like an absolute or direct-reading gage, in which case the indicator displays the feature's actual diameter. Alternately, if the chamfer gage has a digital indicator that allows pre-sets to be entered, then it can still be used for comparative (i.e., plus or minus from nominal) measurements, even if it is mastered on a flat.