GAGING ACCURACY: GETTING READY ONE STEP AT A TIME

Familiarity may not always breed contempt, but in precision gaging, it can certainly lead to error. It happens when we do what we have done a thousand times before, but do it without thinking. We are in a hurry. We grab a gage and take a measurement without stopping to go through those preliminary checks and procedures we know will assure accurate results. We forget that the methodology of measurement is as important as the gage itself. As a machine operator, you must assume much of the responsibility for gaging accuracy. Whenever a gage has not been in frequent use, make sure you follow these basic steps:

- Providing the indicator has been checked for calibration, repeatability and free running, look over the way it is clamped to the test set, comparator frame or gage. Any detectable shake or looseness should be corrected.

- Check for looseness of play in comparator posts, bases, clamping handles, fine adjustment mechanisms and anvils. It is easy, for instance, to rely on the accuracy of a comparator and find afterwards that the reference anvil was not securely clamped down.

- When using portable or bore gages, be sure to check adjustable or changeable contacts to be sure there is no looseness of play.

- If gage backstops are to be used and relied on, make sure they are also clamped tight in the proper location.

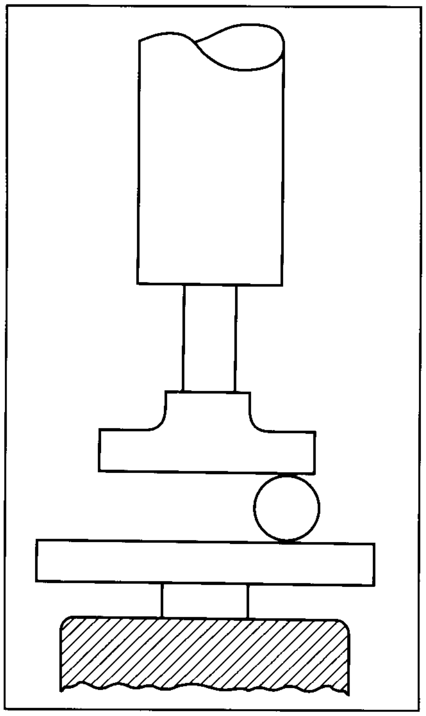
- The sensitive contact points on many portable gages and bench comparators are tipped with wear-resisting tungsten carbide, sapphire or diamond inserts. Test these tips to see that they haven't become loose in previous use. Also, examine them under a glass. If they are cracked, chipped or badly scored, their surface conditions may prevent accurate or repeatable readings. They may even scratch the work.

- If opposing anvils are supposed to be flat or parallel, check them with the wire or ball test. By positioning a precision wire or ball between anvils, you can read parallelism on the indicator simply by moving the wire/ball front to back and side to side.

- One of the easiest chores to neglect is regular cleaning of indicating gages and bench comparators. Yet, as we have often noted in this column, dirt is the number one enemy of accuracy. Dirt, dust, grit, chips, grease, scum and coolant will interfere with accuracy of gage blocks, indicators, and precision comparators. Clean all such instruments thoroughly at each use. Also, be sure to rustproof exposed iron or steel surfaces.

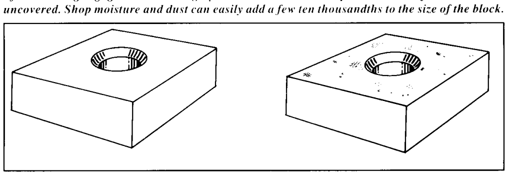
- Take the same steps to ensure the reliability of master discs and master rings as you would for gage blocks. Examine them for nicks and scratches and the scars of rough handling. And handle them as you would gage blocks, as well. After all, they are designed to provide equal precision.

- Finally, if you see a sudden shift in your process during the day, these same basic steps should be part of your troubleshooting routine. And, in this situation, don't automatically assume your gage is correct just because it has a calibration sticker. Strange things do happen and you will do well to investigate all possibilities especially the ones that habit can make us overlook.



Parallelism between the reference and sensitive anvils can be easily explored with a precision steel ball.

After cleaning a gage block thoroughly, leave it out in the shop environment for 30 minutes, uncovered. Shop moisture and dust can easily add a few ten thousandths to the size of the block.



GAGE ACCURACY RUNS HOT AND COLD

"It takes a while to warm up in the morning, but after that, it runs great." I swear I've heard machinists say this of their gages, as if those instruments were like car engines with 50-weight motor oil and cold intake manifolds.

What's really happening, of course, is that the machinist arrives at work, takes his gage and master out of a controlled environment, masters the gage and then gets to work. As he handles it, the gage begins to warm up. Which is not to say that its moving parts move more freely, but instead, that the gage itself expands. Depending on where he keeps his master, and whether or not he re-masters regularly, he will find himself "chasing the reading," possibly for hours, until everything reaches equilibrium.

Thermal effects are among the most pervasive sources of gaging error. Dirt, as a gaging problem, is either there, or it isn't. But everything has a temperature -- even properly--calibrated gages and masters. The problem arises from the fact that everything else has a temperature too, including the air in the room, the workpiece, the electric lighting overhead, and the operator's fingers. Any one of these "environmental" factors can influence the reading.

Why is temperature such a critical concern? Because most materials expand with heat, and they do so at differing rates. For every 10 F rise in temperature, an inch of steel expands by 60 millionths. "Not to worry," you might say, " I am only working to 'tenths'". But aluminum expands at more than twice that rate, and tungsten carbide at about half. Now, what happens to your reading if you are trying to measure a 2-inch aluminum workpiece with a steel-framed snap gage and tungsten carbide contacts, after the workshop has just warmed up to 7 degrees? And by the way, did that workpiece just come off the machine, and how hot is it?

Beats me, too. That's why it's critical to keep the gage, the master, and the workpiece all at the same temperature, and take pains to keep them there.

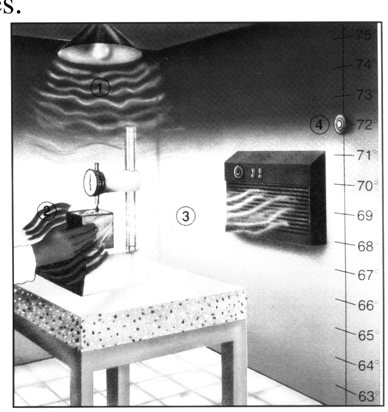
That means keeping an eye on many factors. Don't put your master away like some sacred object. Gage and master must be kept together, to ensure that they "grow" in tandem and to permit frequent re-mastering. Workpieces must have sufficient time to reach ambient temperature after machining, or after being moved from room to room. The operator should avoid handling the gage, master and workpiece more than absolutely necessary.

Care must be taken that sources of heat and cold in the room do not intrude on the process. Incandescent lighting, heat and air conditioner ducts, even a shaft of direct sunlight through a window can alter a whole series of measurements. Keep things at the same "altitude" in the room, to avoid the effects of temperature stratification.

As tolerances tighten, additional measures become necessary. Workpieces should be staged on a heat sink beside the gage and should be handled with forceps or gloves. A Plexiglas shield may be required to protect the gage from the operator's breath. (The heat, that is, not the effects of the sardine sandwich he had for lunch.)

For accurate gaging, be aware of possible sources of thermal "contamination" to the measurement process. While it may not be possible to isolate your gaging process in its own perfectly controlled environment, at least take precautions to minimize the effects of temperature variation on your gages, masters and workpieces.

Thermal sources of error are a major cause of gage performance degradation. Typical thermal sources are: (1) radiant heat from illuminating sources; (2) conductive heat (that is, operator touching workpiece); (3) convection and drafts from heating and cooling systems; and (4) room temperature gradients.



WHAT DO YOU MEAN BY ACCURACY?

How accurate is my gage? How often do you ask yourself that question--checking a dimension on a workpiece, but never fully believing what your gage tells you? You send the piece off and hold your breath while you wait to see if it's accepted or rejected.

Gaging is one of the most critical and least understood operations in machine shops today. Industry can no longer afford yesterday's levels of wastage, and accurate gaging has, therefore, never been more important. With these concerns in mind, I have agreed to write this new column for MMS about gaging issues. In the coming months, we will be looking at a number of important topics including: how to ensure good gaging technique; how to select and use different types of gages; how to identify and correct for sources of error; and how to use gaging to ensure quality, or, "Now that I have got the data, what do I do with it?"

The metrology industry has not been consistent in its definitions, but it's important that we agree on certain terms--all of them related to the concept of accuracy-- before we can converse intelligently about gaging.

Accuracy, itself, is a nebulous term that incorporates several characteristics of gage performance. Our best definition is that accuracy is the relationship of the workpiece's real dimensions to what the gage says. It's not quantifiable, but it consists of the following quantifiable features.

Precision (also known as repeatability), is the ability of a gage or gaging system to produce the same reading every time the same dimension is measured. A gage can be extremely precise and still highly inaccurate. Picture a bowler who rolls nothing but 7-10 splits time after time. That is precision without accuracy. A gage with poor repeatability will on occasion produce an accurate reading, but it is of little value because you never know when it is right.

Closely related to precision is stability, which is the gage's consistency over a long period of time. The gage may have good precision for the first 15 uses, but how about the first 150? All gages are subject to sources of long-term wear and degradation.

Discrimination is the smallest graduation on the scale, or the last digit of a digital readout. A gage that discriminates to millionths of an inch is of little value if it was built to tolerances of five ten-thousandths.

On analog gages, discrimination is a function of magnification which is the ratio of the distance traveled by the needle's point to travel at the transducer. A big dial face and a long pointer--high magnification--is an inexpensive way for a manufacturer to provide greater discrimination. This may create the illusion of accuracy, but it isn't necessarily so.

Resolution is the gage's ability to distinguish beyond its discrimination limit. A machinist can generally estimate the pointer's position between two graduations on a dial, but usually not to the resolution of the nearest tenth of a graduation.

Sensitivity is the smallest input that can be detected on the gage. A gage's sensitivity can be higher than its resolution or its precision.

Calibration accuracy measures how closely a gage corresponds to the dimension of known standards throughout its entire measuring range. A gage with good precision may be usable even it its calibration is off, as long as a correction factor is used.

If we could establish these terms into common shop parlance, there would be better agreement about how accurate a gage is.

MEASURING VERSUS GAGING

We often use the terms "gaging" and "measuring" interchangeably, but for this month, at least, we're going to distinguish between them as different procedures. There are times when gaging is appropriate, and other times when measuring is the way to go. What's the difference?

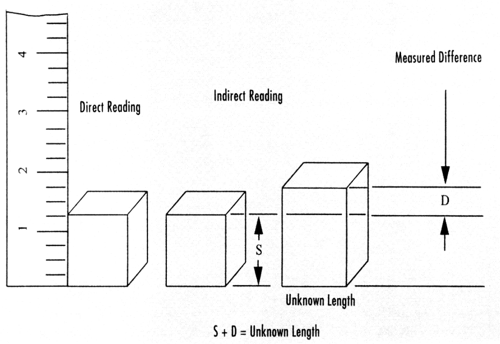
Measuring is a direct-reading process, in which the inspection instrument consists of (or incorporates) a scale—a continuous series of linear measurement units (i.e., inches or mm), usually from zero up to the maximum capacity of the instrument. The workpiece is compared directly against the scale, and the user counts complete units up from zero, and then fractions of units. The result generated by "measuring" is the actual dimension of the workpiece feature. Examples of measuring instruments include steel rules or scales, vernier calipers, micrometers, and height stands. CMMs might also be placed in this category.

Gages, in contrast, are indirect-reading instruments. The measurement units live not on a scale, but off-site (in a calibration lab somewhere), and a master or other standard object acts as their substitute. The workpiece is directly compared against the master, and only indirectly against the measurement units. The gage thus evaluates not the dimension itself, but the difference between the mastered dimension (i.e., the specification), and the workpiece dimension.

Gages fall into two main categories: "hard," and "variable." "Hard" gages—devices like go/no-go plugs and rings, feeler gages, and non-indicating snap gages—are not conducive to generating numerical results: they usually tell the user only whether the part is good or bad. Variable gages incorporate some principle for sensing and displaying the amount of variation above or below the established dimension. All indicator and comparator gages meet this description, as does air and electronic gaging. The result generated by a variable gage on an accurately sized part is generally 0 (zero), not the dimension. Because of modern industry's need for statistical process control, variable gaging is the norm, and there are few applications for hard gaging.

Variable gaging may be further subdivided into fixed and adjustable gaging. Fixed variable gages, which are designed to inspect a single dimension, include mechanical and air plug gages, and many fixture gages. Adjustable variable gages have a range of adjustment that enables them to be mastered to measure different dimensions. Note that range of adjustability is not synonymous with range of measurement. You can use an adjustable snap gage to inspect a 1" diameter today, and a 3" diameter tomorrow, but it would be impractical to constantly re-master the gage to inspect a mixture of 1" and 3" parts. (This would be no problem for most "measuring" instruments, however.) Almost all indicator gages may be of the adjustable variety.

Direct-reading devices, (for example, scales and vernier calipers) read the part's actual dimension. Indirect-reading devices (gages) tell the user how far the part deviates from the standard.



Because of its relative mechanical simplicity, fixed gaging tends to hold calibration longer, and require less frequent maintenance and mastering. It is often easier and quicker to use than adjustable gaging. But it is also inflexible: once a production run has finished, a shop may find it has no further use for a gage designed solely to inspect IDs of 2.2370", ±0.0002".

Where production runs are smaller, or where throughput is not quite so important, adjustable gaging often makes more sense. The range of adjustability allows a gage to be turned toward a new inspection task after the initial one is completed. The adjustable bore gage being used today to measure IDs of 2.2370", ±0.0002" may be used to measure IDs of 1.0875", ±0.0003" next month.

Fixed gaging therefore tends to be economical for inspection tasks that require high throughput, and for production runs that involve many thousands of parts, and that last for months or years. Adjustable gaging tends to be appropriate for shorter production runs, and for smaller shops in general.

Similar issues apply when comparing "gaging" and "measuring." Gaging tends to be faster, both because it is less general-purpose in nature, and because the operator need observe only the last digit or two on a display, rather than count all of the units and decimals up to the present dimension. Because of its generally much shorter range, gaging can also be engineered for higher accuracy (resolution and repeatability) than measuring instruments. For anything resembling a production run, gaging is almost always required. But where single part features must be inspected, measuring devices tend to make more sense. In practice, most shops will find they need some of both types of devices.

COMMONLY ASKED QUESTIONS:

Picking the Right Gage and Master

In this job I get asked a lot of questions. In fact, I did some figuring the other day, and estimate, conservatively, that we have probably answered at least 25,000 gaging questions over the past ten years. Some of these questions have been absolutely brilliant. They have pushed me to learn more about my business and our industry, and to grow professionally. Some have even helped me develop new products. Others have been, well... less brilliant. Those asked most often concern picking gages and masters. We have talked about various aspects of this process in previous columns, but I thought it would be well to list the questions and answer them directly. Then, next time someone calls, I can just read the answers!

Without a doubt, the most common question I am asked has to do with selecting a gage: "I've got a bushing with a .750" bore that has to hold ± 0.001 in. What kind of gage should I use?" There are a number of choices: a dial bore gage, an inside micrometer, an air plug, a self-centralizing electronic plug like a Dimentron®, or any one of several other gages. But picking the right gage for your application depends basically on three things: the tolerance you are working with; the volume of components you are producing; and the degree of flexibility you require in the gaging system.

For tolerance, or accuracy, we go back to our ten-to-one rule: if your tolerance is ±0.001

in., you need a gage with an accuracy rating of at least ten times that, or within one tenth (±0.0001 in.). But that's not all there is to it. The gage you pick may also have to pass your own in-house GR&R (Gage Repeatability and Reproducibility) requirements. Just because we, as gage manufacturers, say a gage is accurate to a tenth, doesn't necessarily mean you, as a component manufacturer, will actually get that level of performance from it in the field. GR&R studies are designed to show how repeatable that specified accuracy is when the gage is used by a number of operators, measuring a number of parts in the manufacturing environment. Since this incorporates the whole idea of 'usability,' it makes the process of selecting a gage more complicated. There is no single standard for GR&R studies, but generally, it is a statistical approach to quantifying gage performance under real life conditions. Often this is expressed as the ability to measure within a certain range a certain percent of the time. As "10%" is a commonly quoted GR&R number, it should be noted that this is quite different from the traditional ten-to-one rule of thumb. But that's a topic for at least a couple of future columns. For our purposes here, suffice it to say that if passing GR&R is one of your requirements, you should discuss the details with your gage supplier.

Component volume is also of prime importance in picking a gage. How big is the job? How long will it last? How important is it to the shop? This will dictate how much you can spend on a gage or gaging system. Generally speaking, the trade-off here is speed and efficiency for cost and flexibility. You can get a system that will measure several hundred parts an hour, twenty-four hours a day, if that's what you need. But that system is not going to be good at measuring a number of different parts, and it's not going to be inexpensive.

The flip side here is flexibility. It may well be that the decision to buy a gage is based not so much on a specific part, but on overall shop requirements. That may be a different gage from one which measures a single-sized hole with optimum efficiency. Finally, consider what you intend to do with the reading once you get it. In short, do you need digital output?

After gages, the next most common question concerns masters: what grade and kind to buy. "Do I need XX or XXX, and what's the difference?" The answer here is a bit more direct. There are several classes or grades of masters, depending on accuracy. These are Z, Y, X, XX, and XXX, with Z being the least accurate and the least expensive. Class XX is the most common, with an accuracy rating of ±0.00001 (up to ±0.00005, depending on size -- see Figure 1). What class you buy is determined, again, by the ten-to-one rule; but based on the gage, not your part. Thus, if your 0.750 in. diameter part has a tolerance of ±0.001 in., pick a gage that is accurate to a tenth (± 0.0001 in.) and a master that is accurate to one-tenth of that, or ten millionths (±0.00001). In this case, that would be a grade XX master.

But now, here's a rub: let's say you have a tolerance of five tenths (± 0.0005 in.) and you are using an air gage with an accuracy of twenty millionths (±0.00002 in.). That is certainly better than ten-to-one for the gage, but what class of master do you use? One that is accurate to two millionths? If so, you've got a problem, because no one makes them. What you do in cases like this is buy a master that is Certified for size. This means it will be accurate to within five millionths (± 0.000005 in.) of the certified size, and will indicate the variation from nominal.

Finally, people continually ask me about chrome plating and carbide. "Why should I pay extra for chrome plating, and when do I need carbide gage blocks or masters?" The answer here is simple, and has to do with the hostility of your gaging environment. Chrome plating protects against corrosion. It is also much more wear resistant than plain steel. So if you have a corrosive or abrasive environment, chrome-plated gages and masters are worth the cost simply because they will last longer.

As for carbide, I generally recommend using blocks and masters of a material similar to the part you are machining, because of thermal expansion. Carbide has a coefficient of thermal expansion about one-third that of steel. If the temperature in the shop changes -- a not uncommon occurrence -- your carbide master will not grow at the same rate as your gage or parts. However, carbide is extremely corrosion resistant. Also, it has the highest wear resistance of any master material now in use. If your environment is so corrosive and violent that steel and even chrome plate do not hold up, carbide may be the answer.

WHAT KIND OF GAGE DO YOU NEED?
A BAKER'S DOZEN FACTORS TO CONSIDER

Like every other function in modern manufacturing operations, inspection is subject to management's efforts at cost control or cost containment. It's good business sense to try to maximize the value of every dollar spent, but it means that hard choices must be made when selecting gaging equipment. Issues as diverse as personnel, training, warranties, throughput requirements, manufacturing methods and materials, the end-use of the workpiece, and general company policies on gaging methods and suppliers may influence both the effectiveness and the cost of the inspection process.

For example, what's the ultimate cost of a bad part passing through the inspection process? It could be just a minor inconvenience to an OEM customer—maybe a two-second delay as an assembler tosses out a flawed two-cent fastener and selects another one. On the other hand, it could be a potentially disastrous equipment malfunction with expensive, even fatal, consequences. Even if the dimensional tolerance specifications for the parts are identical in both instances, management should certainly be willing to spend more on inspection in the second case to achieve a higher level of certainty—probably approaching 100 percent. One disaster averted will easily pay for the more expensive process in lawsuits avoided, lower insurance premiums, etc.

Many companies have achieved economies by moving inspection out of the lab and onto the shop floor. As this occurs, machinists and manufacturing engineers become more responsible for quality issues. Luckily, many gage suppliers are more than willing to spend time helping these newly assigned inspection managers analyze their functional requirements.

One could begin by comparing the hardware options. Let's take as an example a "simple" OD measurement on a small part. This inspection task could conceivably be performed with at least seven different gaging solutions:

1) Surface plate method, using V-blocks and test indicator
2) Micrometer
3) Purpose-built fixture gaging
4) Snap gage
5) Bench-type ID/OD gage with adjustable jaws
6) Hand-held air ring or air fork tooling
7) A fully automated system with parts handling.

(Actually there are many more solutions available, but let's keep it "simple.") Between these options there exists a price range from about $150 to $150,000. There are also differences in gage accuracy, operator influence, throughput, data output, and on and on. It's confusing, to say the least.

A better approach is to first define the functional requirements of the inspection task, and let that steer one toward the hardware that is capable of performing the tasks as identified. In order to do this, the end-user should consider the following factors:

- Nature of the feature to be inspected. Is it flat, round or otherwise? ID or OD? Is it easily accessible, or is it next to a shoulder, inside a bore, or a narrow groove?

- Accuracy. There should be a reasonable relationship between job tolerance and gage accuracy resolution and repeatability—very often on the order of a 10:1 ratio. A requirement for statistical GR&R (gage repeatability and reproducibility) testing may require 20:1. But always remember:

- Inspection costs. These increase sharply as gage accuracy improves. Before setting up a gaging operation for extremely close tolerance, verify that that particular level of accuracy is really necessary.

- Time and throughput. Fixed, purpose-built gaging may seem less economical than a more flexible, multi-purpose instrument, but, if it saves a thousand hours of labor over the course of a production run, it may pay for itself many times over.

- Ease of use, and training. Especially for shop-floor gaging, you want to reduce the need for operator skill and the possibility of operator influence.

- Cost of maintenance. <u>Can</u> the gage be maintained, or is it a throw-away? How often is maintenance required, and who's going to perform it? Gages that can be reset to a master to compensate for wear are generally more economical over the long run than those that lose accuracy through extended use, but may require frequent mastering to ensure accuracy.

- Part cleanliness. Is the part dirty or clean at the stage of processing in which you want to measure it? That may affect labor requirements, maintenance, and the level of achievable accuracy, or it might steer you toward air gaging, which tends to be self-cleaning.

- Gaging environment. Will the gage be subject to vibration, dust, changes in temperature, etc.?

- "Mobility." Are you going to bring the gage to the part, or vice versa?

- Parts handling. What happens to the part after it's measured? Are bad parts discarded or reworked? Is there a sorting requirement?

- Workpiece material and finish. Is the part compressible? Is it easily scratched? Many standard gages can be modified to avoid such influences.

- Manufacturing process. Every machine tool imposes certain geometric and surface finish irregularities on workpieces. Do you need to measure them, or at least take them into consideration when performing a measurement?

- Budget. What do you have to work with?

All of these factors may be important when instituting an inspection program. Define as many as you can to help narrow the field, but remember that help is readily available from most manufacturers of gaging equipment—you just have to ask.

GAGING ID'S AND OD'S

Without a doubt, circles are the most frequently produced machined form, generated by many different processes, including turning, milling, centerless grinding, boring, reaming, drilling, etc. There is, accordingly, a wide variety of gages to measure inside and outside diameters. Selecting the best gage for the job requires a consideration of many variables, including the size of the part, the length or depth of the round feature, and whether you want to gage in-process or post-process.

ID/OD indicator gages come in two basic flavors: benchtop and portable, as shown in Figures 1 and 2. Benchtop gages are generally restricted to measuring parts or features not more than 1" deep or long, while portable ID/OD gages can go as deep as 5" or so. If you need to measure hole IDs deeper than that, bore gages or plug gages are the tool of choice. On the other hand, snap gages are commonly used for ODs on longer parts — shafts, for example.

Getting back to ID/OD gages, the choice between benchtop and portable styles depends mainly on the size of the part being measured, and whether the part will be brought to the gage, or vice versa. If the part is large or awkward to manipulate, or if it's set up on a machine and you want to measure it there, then a portable, beam-type gage is required. Beam-type gages are available with maximum capacities from 5" to about 5', the largest ones being used to measure bearings and castings for jet engines and similarly large precision parts. Range of capacity is typically about 6", while the measurement range is determined by the indicator installed.

Most portable ID/OD gages lack centralizing stops, so they must be "rocked" like a bore gage to find the true diameter. When rocking the gage, use the fixed contact as the pivot, and allow the sensitive contact to sweep across the part. Likewise, if the gage must bear its own weight against the part, make sure that weight is borne by the fixed contact, not the sensitive one.

A special fixture with sliding stops at major increments is used to master for large ID measurements. Gage blocks are inserted in the fixture to "build out" the desired dimension. For OD measurements, calibrated "end rods" are often used: there is nothing especially fancy about these rods — they're simply lengths of steel, carefully calibrated for length. When mastering and measuring at large dimensions, the gage, the master, and the part must all be at the same temperature. Otherwise, thermal influences will throw off the measurement.

Even so, don't expect very high precision when measuring dimensions of a foot or more. Most indicators on these large-capacity gages will have minimum grads of .0005". This is adequate, given the inability of most machine tools to hold tolerances much tighter than about .002" for parts that large. Beware the gage maker who tries to sell you a 3-foot capacity ID/OD gage with .0001" resolution: it's probably not capable of repeatable measurements.

Benchtop gages are used for smaller parts (diameters ranging from about .25" to about 9" maximum), and they're capable of higher precision. (.0001" is readily achievable.) There are two basic benchtop configurations: T-plates, and V-plates. A T-plate gage has sensitive and fixed contacts oriented normally, at 180_ from each other, to measure true diameters. An extra fixed contact, oriented at 90_ or 270_, serves to aid part staging. A V-plate gage has two fixed contacts offset symmetrically from the centerline, and the part is held against both of them. This arrangement requires a special-ratio indicator, because motion at the sensitive contact is actually measured relative to a chord between the fixed contacts, not to a true diameter.

This three-point arrangement is useful if the production process is likely to induce a three-lobed condition on the part — for example, if the part is machined in a three-jawed chuck. By rotating the part in a V-plate gage, one can obtain an accurate assessment of deviation from roundness. If the process is expected to generate an even number of lobes, then the T-plate layout is more appropriate to measure deviation.

Because they are self-centralizing, benchtop gages are capable of rapid throughput. To further accelerate gaging with either benchtop or portable gages, mechanical dial indicators can be replaced with electronic indicators. The dynamic measurement capabilities of the latest generation of digital indicators enable them to capture the minimum or maximum reading, or calculate the difference between those two figures. Operators are thus freed from having to carefully monitor the motion of a rapidly - swinging needle on a dial indicator when rocking a portable gage, or checking for deviation on a benchtop version.

GAGE CONTACTS: GET THE POINT?

In spite of their apparent simplicity, gage contacts represent a source of many potential measurement errors. When the simple act of touching a part can change its dimension, it's important to understand the ramifications of contact selection and application.

The first consideration must be whether you actually touch the part. Air gaging, as a non-contact method, has many advantages but is not always appropriate. Air gaging tends to average out surface finish variations on a part, providing a reading that lies between the microinch-height peaks and valleys. In some instances this may be desirable, but if the critical dimension lies at the maximum height on the surface, then contact gaging might be more appropriate.

Contact size and shape are critical. Contacts with small radii may nestle between high spots of surface and form irregularities, or might sit on top of them, depending on exactly where the gage contacts the workpiece. If the critical dimension is the low spot, it may be necessary to explore the part with the gage. Larger radii or flat contacts will bridge across high spots. The choice of radius depends at least partly on whether you want to "ignore" surface and geometry irregularities on the high or low side.

Contact size and shape also influence measurements because all materials compress to some extent as a function of pressure. When measuring obviously compressible materials such as plastics or textiles, gaging practice is commonly guided by industry standards. For example, ASTM D-461, "Standard Methods of Testing Felt," specifies the size of the bottom anvil (min. 2 in^2), the size and shape of the upper contact (1 = 0.0001 in^2; i.e., 1.129" diameter, with edge radius of 0.016 = 0.001 in^2), the force of the contact (10 = 0.5 oz.), and the amount of time allowed for material compression prior to taking the measurement (min. 10 sec.). Similarly detailed standards exist for measuring the thickness of wire insulation, rubber sheet stock, and dozens of other materials. Not all the contacts defined in the standards are flat, parallel surfaces: other shapes such as knife-edges, buttons, cylinders, or spheres may be specified.

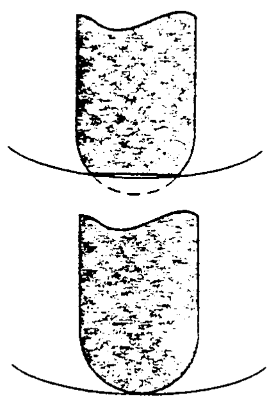
Even materials that are not thought of as compressible do compress somewhat under normal gaging pressures. Because of the higher and higher levels of accuracy required in metalworking industries, it is often essential to compensate for this.

Under a typical gaging force of 6.4 ounces, a diamond-tipped contact point with a radius of 0.125" will penetrate a steel workpiece or gageblock by 10 microinches. The same contact will compress tungsten carbide by 6.6 microinches, and fused quartz by 20 microinches. If microinches count in your application, it is important that workpiece and master be of the same material. Alternately, one can refer to a compensation table to make the necessary adjustment to the gage reading. Compression can be minimized by using a contact with larger surface area.

Contact material also makes a difference. For the sake of durability, one normally selects a contact point that is harder than the workpiece. Typical choices include (in increasing order of hardness): hardened steel, tungsten carbide, and jewelled tips — ruby, sapphire, or diamond. Tungsten carbide is a good choice for measuring steel parts unless millions of cycles are anticipated, in which case diamond might be chosen for longer life. One should avoid using tungsten carbide contacts on aluminum parts, however. Aluminum tends to "stick" to carbide, and it can build up so quickly as to throw off measurements between typical mastering intervals. Hardened steel or diamond are better choices for measuring aluminum.

As shown in Figure 1, differently shaped parts may produce different readings, even though they are dimensionally identical. This is especially true when the contact points are worn. It is often possible to obtain accurate gage readings with worn contacts if one masters carefully and frequently. This includes using a master that is the same shape as the workpiece. Periodically confirm that the gage contacts are parallel by sliding a precision steel ball or wire on the anvil from 12 o'clock to 6 o'clock, and from 3 o'clock to 9 o'clock, and measuring for repeatability. Measure again with the ball in the middle of the anvil to check for wear there.

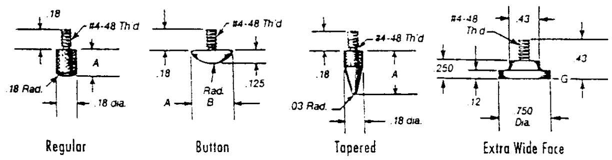
Fig. 1



Make sure the contact is screwed firmly into its socket so there is no play. On rare occasions, a jeweled insert may come slightly loose in its steel holder. A simple repeatability check will detect this. Unfortunately, there's no good fix for it. Give the diamond to your sweetheart, and install a fresh contact.

Not all gages use perpendicular motion. If yours has angular motion, be aware that changing the length of the lever contact will change the reading. On mechanical test indicators, you may be able to install a new dial face with the proper magnification, or you can apply a simple mathematical compensation to every measurement. If you're using a lever-type electronic gage head, you might be able to program the compensation into the amplifier.

Fig. 2



A PHYSICAL CHECK-UP FOR GAGES

Just like the people who use them, gages should have periodic physical examinations. Sometimes, gage calibration is needed to identify the seriousness of a known problem, and sometimes it uncovers problems you didn't know existed. But as with a people-exam, the main reason for the annual check-up is to prevent problems from occurring in the first place.

The accuracy of a gage can only be known by reference to a higher standard. Thus, gages are set to masters that are more accurate than the gage. These masters are certified against gage blocks produced to a higher standard of accuracy—ultimately traceable to nationally or internationally recognized "absolute" standards that define the size of the dimensional unit. This is the line of traceability, which must be followed for calibration to be valid.

Calibration is used to determine how closely a gage adheres to the standard. When applied to a master ring, disc, or a gage block, it reveals the difference between the nominal and the actual sizes. When applied to a measuring instrument such as a comparator, calibration reveals the relationship between gage input and output—in other words, the difference between the actual size of the part and what the gage says it is.

Gages go out of calibration through normal usage: parts wear, and mechanisms become contaminated. A gage may have a design flaw, so that joints loosen frequently and the gage becomes incapable of holding calibration. Accidents and rough handling also put gages out of calibration.

No gage, therefore, can be relied upon if it has not been calibrated, or if its calibration history is unknown. Annual calibration is considered the minimum, but for gages that are used in demanding environments, gages that are used by several operators or for many different parts, and gages used in high-volume applications, shorter intervals are needed. Frequent calibration is also required when gaging parts that will be used in critical applications, and where the cost of being wrong is high.

Large companies that own hundreds or thousands of gages sometimes have their own calibration departments, but this is rarely an economical option for machine shops. In addition to specialized equipment, in-house calibration programs require a willingness to devote substantial employee resources to the task.

Calibration service providers are usually a more economical approach. Smaller gages can be shipped to the provider, while large instruments must be checked in-place. Calibration houses also help shops by maintaining a comprehensive calibration program, to ensure that every gage in the facility is checked according to schedule, and that proper records are kept.

General guidelines to instrument calibration procedures appear in the ISO 10012-1 and ANSI Z540-1 standards. While every gage has its own specific procedures which are outlined in the owner's manual, calibration procedures also must be application-specific. In other words, identical gages that are used in different ways may require different procedures.

For example, if a gage is used only to confirm that parts fall within a tolerance band, it may be sufficient to calibrate it only at the upper and lower tolerance limits. On the other hand, if the same gage is used to collect data for SPC, and the accuracy of all measurements is important, then simple calibration might be insufficient, and a test of linearity over the entire range might be needed.

The conditions under which calibration occurs should duplicate the conditions under which the gage is used. Calibration in a high-tech gaging lab may be misleading if the gage normally lives next to a blast furnace. Similarly, a snap gage that is normally used to measure round parts should be calibrated against a master disc or ring, and not with a gage block. The gage block could produce misleading results by bridging across worn areas on gage contacts, while a round master would duplicate the actual gaging conditions and produce reliable results.

Before calibration begins, therefore, the technician should be provided with a part print and a description of the gaging procedure. Next, he should check the calibration record, to confirm that the instrument serial number and specifications agree with the instrument at hand. The gage will then be cleaned and visually inspected for burrs, nicks, and scratches. Defects must be stoned out, and mechanisms checked for freedom of movement. If the instrument has been moved from another area, it must be given time to stabilize.

All of these measures help ensure that calibration will be accurate, but this must not lead to a false sense of security: gage calibration will not eliminate all measuring errors. As we have seen before, gaging is not simply hardware: it is a process. Calibration lends control over the instrument and the standard or master, but gage users must continue to seek control over the environment, the workpiece, and the gage operator.

SQUEEZING MORE ACCURACY FROM A GAGING SITUATION

All gages are engineered to provide a specified level of accuracy under certain conditions. Before specifying a gage, users must take stock of all the parameters of the inspection process.

How quickly must inspection be performed? Many gages which are capable of high levels of accuracy require careful operation to generate reliable results. Others are more foolproof, and can generate good results more quickly, and with less reliance on operator skill.

Where will inspection take place? Some gages are relatively forgiving of environmental variables—for example, dust, cutting fluid residues, vibration, or changes in temperature—while others are less so. Likewise with many other factors in the gaging situation. The ability to obtain specified accuracy from a gage in a real inspection situation depends upon the prior satisfaction of many parameters, both explicit and assumed.

Recently, a manufacturer came to me with a requirement to inspect a wide variety of hole sizes on a line of 4-liter automotive engines. Some of the relevant parameters of the gaging situation included:

- **Throughput**. With literally hundreds of thousands of parts to measure, inspection had to be fast and foolproof.
- **Output**. The manufacturer required the capability of automatically collecting data for SPC.
- **Portability**. The parts being gaged were large, so the gage had to come to the parts, not vice versa.
- **Accuracy**. Most hole tolerances were ±0.001", but some were as tight as ±0.0005".

  Adjustable bore gaging wouldn't do the job, because of slow operation and a high requirement for operator skill. Air gaging, while fast and sufficiently foolproof, was not sufficiently portable for the application. We settled on fixed-size mechanical plug gaging, equipped with digital electronic indicators to provide data output.

The manufacturer specified a GR&R (gage repeatability and reproducibility) requirement of 20% or better on holes with tolerances of ±0.001". This meant that the system had to perform to 80-microinches or better. This requirement was met using standard gage plugs, and standard digital indicators with resolution of 50microinches: GR&R achieved with these setups was _16%.

On holes with tolerances of ±0.0007" and ±0.0005", however, the manufacturer required GR&R of 10%, which translated to 40-microinches. Given the other parameters of the application, mechanical plug gages remained the only practical approach, so we had to find a way to "squeeze" more accuracy out of the situation.

Plug gages are typically engineered for 0.002" of material clearance in the holes they are designed to measure, to accommodate undersize holes, and to ease insertion. The greater the clearance, the greater the amount of centralizing error, in which the gage measures a chord of the circle, and not its true diameter. By reducing the designed clearance, centralizing error can be minimized—with some tradeoff against ease of insertion.

We engineered a special set of plug gages, with minimum material clearance of 0.0007". The standard digital indicators were also replaced with high-resolution units, capable of 20microinch resolution. This combination satisfied the requirements, generating GR&R of _8.5%.

Remember SWIPE? This acronym stands for the five categories of gaging variables: Standard (i.e., the master); Workpiece; Instrument (i.e., the gage); Personnel; and Environment. In the case of the engine manufacturer, we tweaked the instrument, thus reducing one source of gaging variability. We reduced a second source by providing higher-quality masters for these gages. If throughput had not been such a high priority, we might have considered altering the environment where inspection was performed, or providing more training to personnel. If portability hadn't been an issue, then the solution might have been a different instrument altogether.

The five categories of gaging variables encompass dozens of specific factors. (For example, within the category of Workpiece, there are variables of surface finish and part geometry that may influence dimensional readings.) To squeeze more accuracy out of a gaging situation, look for opportunities to reduce or eliminate one of more of these factors.

THE REAL DIRT ABOUT GAGING

I am not sure that any of us in the metrology business are very close to godliness, but I do know that cleanliness is the first step to approaching accuracy in gaging. Probably every machinist is at least nominally aware that dirt can interfere with the ability to take accurate measurements. But the importance on the issue cannot be over-emphasized, and even a conscientious user can occasionally use a reminder.

Leave your gage out of its box for a few hours. Then check it for zero setting. Next, clean the measuring surfaces and blow off the lint. Check the zero setting again. You will probably find a difference of about 0.0005” due to dirt on these surfaces.

Test number two: We left a clean master disc, marked 0.7985”XX unprotected for a number of hours on a work bench ion the shop. Then, taking special pains not to touch its measuring surfaces, we brought it into a temperature controlled room and let it cool off before measuring it with an electronic comparator. The needle went off the scale, which meant that the master plus dirt was more than 0.0003” larger than the nominal 0.7985” setting. Then we carefully and thoroughly cleaned the master with solvent and measured it again. The reading was +0.000004 from nominal.

Finally, we cleaned the master again, using the time-honored machinist’s method of wiping it with the palm of the hand. Measuring again, it had gone up to +0.000013”. We lost half the normal gage tolerance by “cleaning” it with the palm. (Some slight error may also have been introduced through expansion of the master due to conductive heating from the hand. More on this subject in a later column).

We have already seen how dirt in invisible quantities can skew a measurement, both on the contacting surfaces of the gage itself and on the workpiece or master. And recall that our examples were reasonably clean environments. Now picture the common abode of a gage in your shop: Is it living in an oil-and-chip-filled apron of a lathe or screw machine, or perhaps sharing the pocket of a shop apron with pencil stubs, pocket lint and what have you?

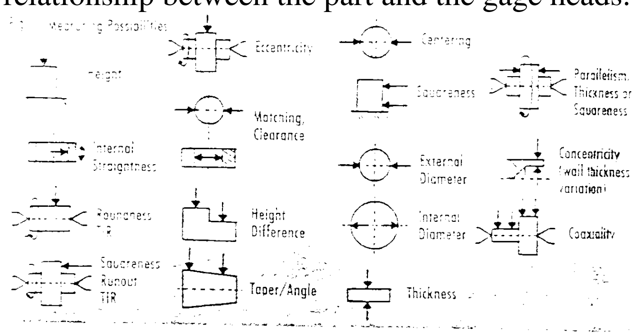
Aside from simply getting in the way of a measurement, dirt also impedes accurate measurement by increasing friction in a gage’s movement. Drag may prevent a mechanism from returning to zero, and every place that friction must be overcome represents a potential for deflection in the gage or the setup. If dirt is the biggest enemy of accurate measurement, then friction is a close second.

Next time you have a serviceman in to work on a gage, watch him. Chances are, the first thing he does is clean the gage, whether it is a simple dial indicator or a Coordinate Measuring Machine. If you take only one thing away from this column, this should be it. Eliminate dirt as a possible source of error before attempting to diagnose a malfunctioning gage.

GAGE LAYOUT IS UP TO THE USER

The last two installments of this column have discussed how most dimensional gaging applications are really just variations on four basic themes, to measure height, depth, thickness, or diameter. Relational gaging applications are nearly as straightforward, conceptually. Measuring qualities like roundness, straightness, squareness, taper, parallelism, or distance between centers is usually a matter of measuring a few dimensional features, then doing some simple calculations.

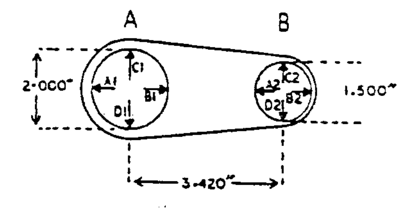
Better yet, let the gage do the calculations. Even simple benchtop gaging amplifiers can measure two or more dimensions simultaneously and manipulate the readings through addition, subtraction, or averaging. (Air gaging can also be used in many of these applications, but for simplicity, we'll stick with electronic gage heads as the basis of discussion.) As shown in the schematics of Figure 1, a wide range of relational characteristics can be measured with just one or two gage heads: it's basically a question of setting them up in the right configuration -- and making sure that the fixture is capable of maintaining a precise relationship between the part and the gage heads.



With a little imagination, you can combine several related and/or independent measurements into a single fixture to speed up the gaging process. Figure 2 shows a fixture gage for measuring connecting rods. Transducers A1 and B1 measure the diameter of the crank bore: out-of-roundness can be checked by comparing that measurement with a second diameter at 90_ (C1 and D1). The same features are measured on the pin bore, using transducers A2 through D2. Finally, the distance between bore centers can be calculated, using the same gaging data.

Using these principles, machine shops can develop workable fixture gages in-house for a wide range of applications, or modify existing gages to add capabilities. Electronic gage heads (i.e., transducers) and air probes are available in many configurations and sizes, some of them small enough to permit simultaneous measurements of very closely -spaced part features. Before you begin in earnest, you'll need to check the manufacturer's specs for gage head dimensions, accuracy, and range. Even if you don't want to build the gage in-house, you can use these ideas to design a "schematic" gage to aid you in your discussions with custom gage makers.

Fig. 2



STAGE IT TO GAGE IT

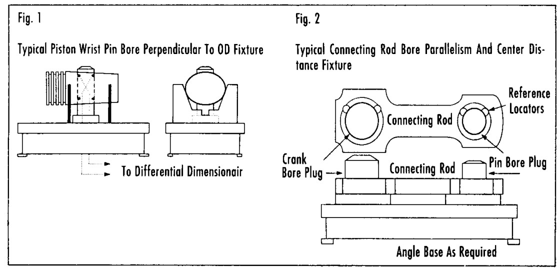
Freedom is not always a good thing, at least when it comes to gaging. Some gaging applications call for inspecting a part for variation across a given feature, which calls for freedom of movement in at least one plane. Other applications call for measuring a series of parts at exactly the same location on the feature, time after time. In the first instance, you're checking the accuracy of the part. In the second, where you're checking the repeatability of the process, freedom of movement is the enemy.

For example, to inspect a nominally straight bore for taper error, using an air gaging plug or a Dimentron®-type mechanical plug, insert the plug slowly, and watch the indicator needle or readout display for variation as you go. On the other hand, if you are inspecting IDs to confirm the stability of the boring process from part to part, you must measure every bore at exactly the same height. If you do not, any taper present may lead you to an erroneous conclusion that the process is unstable. The first application requires freedom of axial movement. The second requires that axial movement be eliminated. This can be readily done by installing a stop collar on the plug, to establish a depth datum.

The number and type of datums required varies with the type of gaging and the application. Figure 1 shows a fixture gage to check a piston for perpendicularity of the wrist pin bore to the piston OD. (Piston skirts are typically ovoid: this is shown exaggerated. The skirt's maximum OD equals the head OD, which is round to the centerline of the pin bore.) The bore is placed over an air plug, which serves as a datum, locating the part both lengthwise and radially. The critical element in the engineering of the gage is in the dimensioning of the two V-blocks that establish the heights of both ends of the part. Because of the skirt's ovality, the V-block at that end must be slightly higher, to bring the OD of the head of the piston perpendicular to the plug. Without reliable staging in this plane, the gage could not generate repeatable results.

As many as three datums may be required to properly locate a part and a gage relative to one another in three dimensional space. Refer to Figure 2. This air fixture gage checks connecting rod crank and pin bores for parallelism (bend and twist) and center distance. Placing the conrod flat on the base establishes the primary datum. Although it is not shown in the diagram, the base is angled several degrees toward the viewer: the uppermost ODs of the plugs therefore establish a secondary datum against which the conrod rests. Two precision balls are installed on each plug, located at a height half the depth of the bores. These balls locate the part lengthwise, establishing a tertiary datum.

Before a fixture gage can be designed, the engineer must understand what specifications are to be inspected. In many respects, the design of the gage mirrors not only the design of the part, but also the manufacturing processes that produced it. Machinists must establish datums in order to machine a part accurately, and gage designers often need to know what those datums were, in order to position the part repeatably relative to the gage head or other sensitive device. When working with a custom gage house, therefore, operation sheets should be provided, in addition to part prints. If you're working with an in-house "gage maker" or a less experienced supplier, make sure that the staging is designed around a careful analysis of the part and processes.



FIXTURES ARE A COMMON SOURCE OF GAGING ERROR

As a gaging engineer, my concept of a gage includes both the measuring instrument and its fixture. Assuming you are dealing with a reputable supplier and your instrument was engineered to do its job as intended, there is probably little you can do to improve its accuracy, aside from throwing it out and spending more money. So we will concentrate on the setup, which is a common source of measurement errors.

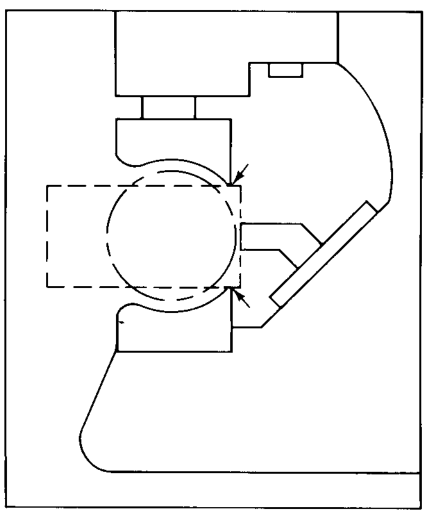
The fixture establishes the basic relationship between the measuring instrument (that is, a dial indicator) and the workpiece, so any error in the fixture inevitably shows up in the measurements. Many fixtures are designed as a variation of a C-frame shape and, as such, have a substantial cantilever that is subject to deflection. This problem is greatly reduced if the fixture is a solid, one-piece unit.

Most fixtures, however, consist of a minimum of three pieces: a base, a post, and an arm. These components must be fastened together with absolutely no play between them. As a rough rule of thumb, any movement between two components will be magnified at least tenfold at the workpiece. Play of only a few millionths can, therefore, easily accumulate through a couple of joints so that measurements to ten-thousandths become unreliable, regardless of the level of discrimination of the instrument.

Because such tight tolerances are required -- tighter than you can perceive by eye or by touch -- it is often essential that fixtures have two setscrews per joint. No matter how tightly a single setscrew is tightened, it often acts merely as a point around which components pivot.

Lost motion due to play between fixture components is dangerous. Assuming that the gage is mastered regularly, a fixture with loose joints may still provide accurate comparative measurements. There are two places in a gage, however, where loose assembly may produce erratic readings, making the setup completely unreliable. Most dial indicators offer optional backs and sensitive contacts that are designed to be changed by the end-user. Looseness of these two components is among the most common sources of gaging error. These are often the first places a gage repair person looks to solve erratic readings.

Fig. 1—After repeated measurements, round workpieces may create wear in the measurement surface. Size setting with gage blocks will not detect this wear, bridging these surfaces.

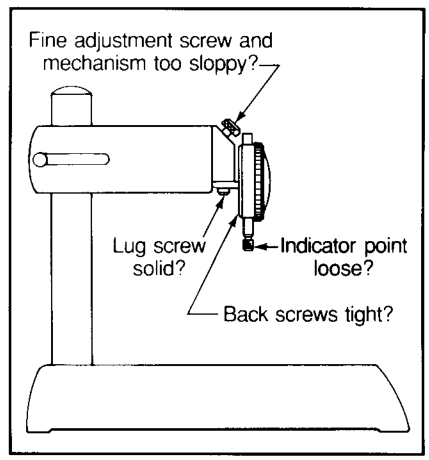


Fixtures must be designed to position workpieces consistently in relation to the measuring instrument. This is critical if the master is a different shape from the workpiece. For instance, when using a flat gage block to master an indicator that is used to check ODs on round workpieces, the fixture must position the workpiece to measure its true diameter-- not a chord.

The use of masters that are the same shape as the workpiece avoids this problem and another one that can be more difficult to isolate. After repeated measurements, round workpieces may wear a hollow, allowing accurate comparative measurements, while flat gage blocks may bridge the wear, introducing a source of error.

Regardless of its complexity, your gage fixture is the key to accurate measurements. Make sure there is no play at its joints. Check that the instrument, itself, is assembled securely. And confirm that the gage measures workpieces and masters at identical locations.

Fig. 2—Loose screws are a common source of gaging error.



GAGING ACCURACY IS SPELLED S-W-I-P-E

When a gaging system is not performing as expected, we often hear the same dialogue. The operator, who has only his gage to go by, says, "Don't tell me the parts are no good-- they measure on my gage." The inspector replies, "Well, the parts don't fit, so if your gage says they are okay, your gage is wrong."

This is the natural reaction. People are quick to blame the instrument because it is easy to quantify. We can grab it, take it to the lab and test it. However, this approach will often fail to find the problem, or find only part of it, because the instrument is only one-fifth of the total measuring system.

The five elements of a measuring system can be listed in an acronym. SWIPE, and rather than immediately blaming the instrument when there is a problem, a better approach is to examine all five elements:

S represents the standard used when the system is set up or checked for error, such as the master in comparative gages of the leadscrew in a micrometer. Remember, master disks and rings should be handled as carefully as gage blocks, because nicks and scratches can be a significant contributor to error.

W is the workpiece being measured. Variations in geometry and surface finish of the measured part directly affect a system's repeatability. These part variations are difficult to detect, yet can sometimes manifest themselves as apparent error in the measuring system. For example, when measuring a centerless ground part with a two-jet air ring, a three-point out-of-round condition will not show up because you are only seeing average size.

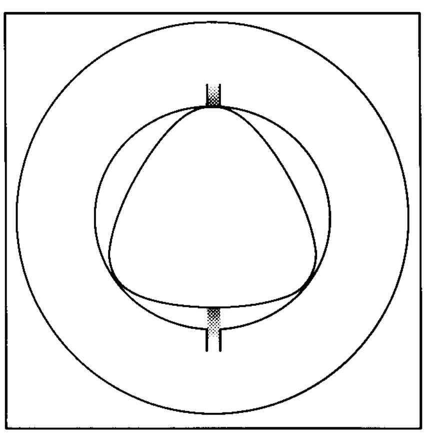


Fig. 1—Variations in geometry and surface finish of the workpiece can directly affect a size measurement. For example, when measuring a centerless-ground part with a two-jet air ring, a three-point out-of-round condition will not show up because you are only seeing average size.

I stands for the instrument itself. Select a gage based on the tolerance of the parts to be measured, the type of environment and the skill level of the operators. And remember what your customers will be measuring the parts with. Say, for example, you are checking bores with an air gage, but your customer inspects them with a mechanical gage. Since the surface is not a mirror finish, your air gage is giving you the average of the peaks and valleys, while the customer's mechanical gage is saying the bores are too small because it only sees the peaks. Neither measurement is "wrong", but you could end up blaming each other's instruments.

P is for people. Failure to adequately train operating personnel will ensure poor performance. Even the operation of the simplest of gages, such as air gaging, requires some operator training for adequate results. Most important, the machine operator must assume responsibility for maintaining the instruments. Checking for looseness, parallelism, nicks and scratches, dirt, rust, and so on, is absolutely necessary to ensure system performance. We all know it, but we forget when we are in a hurry.

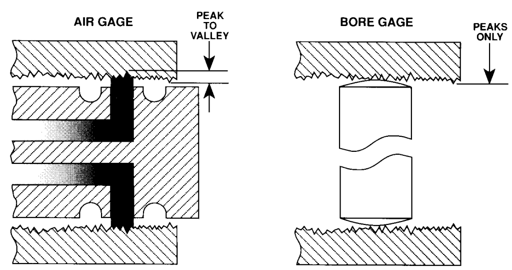


Fig. 2—Remember to use the same gage as your customers, or you could end up blaming each other's instruments. For example, checking bores with an air gage gives the average of the peaks and valleys, while the customer's mechanical gage says the bores are too small because it only sees the peaks.

E represents the environment. As I have said before in this column, thermal factors such as radiant energy, conductive heating, drafts and room temperature differentials can significantly impact gage system performance. And, again, dirt is the number one enemy of gaging. So the problem that has you pulling your hair out and cursing your instruments could be as simple as your shop being a little warmer or a little dustier than your customer's.

Before blaming your gage, take a SWIPE at it and consider all the factors influencing its accuracy.

MAGNIFICATION, DISCRIMINATION, ETC.

Gage users occasionally make the mistake of equating the accuracy of an instrument to the characteristics of its display, whether the display is a dial indicator or a gaging amplifier's digital readout. But while the display is an important aspect of accuracy, the two are far from synonymous. To ensure gaging accuracy with analog devices, it is essential to understand the relationship between gage discrimination, resolution and magnification.

Discrimination is the degree of fineness to which a scaled instrument divides each unit of measurement. For example, inches are a common unit of measurement on steel scales. The scale typically divides each unit, or discriminates, into graduations (grads) of 1/8 inch, 1/16 inch or finer.

Resolution is the ability to read at or beyond the level of discrimination. Keeping with the same example: The steel scale may have 1/8 inch grads, but most people can make a fair estimate of a measurement that falls between two grads, much of the time. In other words, they can resolve to 1/16 inch.

At the opposite extreme, a steel scale could have graduations of 1/128 inch, but few users can resolve to that level of discrimination.

The application of the instrument affects resolution. When measuring the diameter of a nominal 2 inch shaft, a steel scale with 1/64 inch grads can resolve to 1/64 inch, but only when it is placed square across the end of the shaft. If the diameter must be measured at the middle of the shaft with the same scale, resolution will probably be on the order of 1/8 inch.

Luckily, dimensional gages exist to increase the resolution of measurements. They do this by magnifying, or amplifying, motion between the sensitive contact point and the indicator's hand. Dial indicators make it possible to resolve variations of 0.0001 inch on a workpiece, because magnification is on the order of 625:1, so that the width of each 0.0001 inch graduation is about 1/16 inch.

As with a steel scale, however, discrimination on a dial indicator is not necessarily synonymous with resolution. Many users can tell if the pointer falls halfway between two 0.0001 inch grads, thus resolving to .00005 inch, and some claim to be able to resolve to one fifth of a grad, or .00002 inch. But "splitting grads" in this way is pushing beyond the limits of a gage's accuracy.

To eliminate this potential source of human error, no measuring instrument should be used beyond its capability for discrimination. In fact, gages should be selected that discriminate to a finer level than the measurement units required by the application. Measurements are generally considered reliable only to the level of plus or minus one unit of discrimination. So, for example, if measurements to .001 inch are required, the indicator should discriminate to .0005 inch or better.

As a matter of practical analog gage design, as discrimination and magnification increase, the measurement range must decrease. A dial indicator with a measurement range of .1 inch (per revolution) typically has 100 grads on the dial: that is, discrimination of .001 inch. If we wanted to put 1,000 grads on an indicator with the same range of .1 inch and still make it readable, we would need to make it about 22 inches in diameter. As this is not very practical, and we still want an indicator that discriminates to .0001 inch, we will have to restrict the measurement range. The requirements can be stated by the equation:

magnification x range = dial length

But higher magnification and higher resolution at the display do not necessarily translate into higher accuracy. All gages are subject to numerous sources of error. Some of these are external--for example, calibration uncertainty. Gages are also subject to internal sources of error, such as friction, lost motion, and hysteresis (that is, backlash error). These cause errors of linearity, repeatability (that is, precision) and sensitivity--which is the amount of movement at the sensitive contact required to register a change on the display. Higher magnification increases the effects of these errors.

When specifying a gage, therefore, the goal is to select a display with sufficient magnification to provide the required level of discrimination, while avoiding excessive magnification that would produce irregular or misleading data.

CORRECTING FOR COSINE ERROR IN LEVER INDICATOR MEASUREMENTS

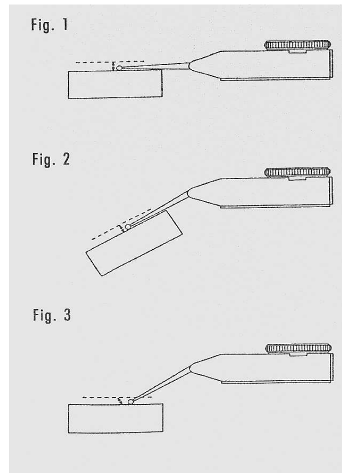
The lever-type test indicator is among the basic tools for comparative measurement. Extremely versatile and capable of high accuracy, mechanical test indicators (and their close cousin, the electronic lever-type gage head) are commonly used with height stands for both dimensional and geometry measurements, and in many machine setup tasks. Although they are generally easy to use, test indicator measurements are subject to a common source of error called cosine error.

Cosine error occurs when the contact arm is not set in the proper relationship to the part. As shown in Figure 1, the arm should be set parallel to the part surface, so that contact tip movement is essentially perpendicular to the part, as the part dimension varies. This is usually easy to arrange, because the arm is held in place by a friction clutch, and can be readily adjusted even if the body of the test indicator is at an angle to the part (Figure 2).

But when the arm is at an angle to the part (Figure 3), the contact tip is also displaced <u>across</u> the part surface as the dimension varies, increasing the apparent deviation from nominal, as registered by the indicator. The steeper the angle, the greater the cosine error.

There are circumstances, however, where it is not possible to set the contact arm parallel to the workpiece because of some interference, like that shown in Figure 4. When this is the case, two options are available.

A special contact with an involute tip (shaped somewhat like a football) automatically corrects for cosine errors up to 20° from parallel. This is often the easiest solution to the problem. Where the angle is greater than 20°, or where the angle is less than 20° but an involute-tipped contact is unavailable or inconvenient to use, a couple simple formulas may be applied to calculate and correct for cosine error.



Cosine Error Correction = displayed measurement x cosine (angle)

Difference = displayed measurement – Cosine Error Correction

Cosine Error Correction is a simple, one-step formula to calculate the part's actual deviation from nominal—in other words, the correct measurement. The Difference formula calculates the error itself.

Depending upon the tolerances involved and the critical nature of the measurement, the angle of the contact arm to the part may be estimated by eye, or with a protractor. (Generally speaking, if they *look* parallel, it's close enough.) Remember that, if you're using the formulas to calculate cosine error, you must use a standard contact with a ball-shaped tip, not an involute tip. Let's run through an example.

The part spec is 1.000" ±0.009". The contact arm is at 30° to the part. The indicator reads +0.010".

Cosine Error Correction = 0.010" x cosine 30° = 0.010" x 0.866 = 0.00866"

Difference = 0.010" – 0.00866" = 0.00134"

The gage reading is off by 0.00134", and the actual deviation from nominal is 0.00866", not 0.010" as displayed. In other words, the part is within tolerance, even though the gage says it's out of tolerance. In this case, failure to recognize and correct for cosine error would result in rejecting a good part. The opposite situation could also apply, in which bad parts would be accepted.

At shallow angles, cosine error is usually small enough to ignore. For example, at a 5° angle, and an indicator reading of 0.010", the Difference is only 15 microinches—far below the ability of most mechanical test indicators to resolve or repeat. In general, it's easier to rely on an involute tip to correct for errors at low angles, and save the formula for instances where it's not possible to orient the contact arm within 20° of parallel to the part. But whichever method is used, make sure that cosine error is understood and corrected.

CENTRAL INTELLIGENCE

Many factors influence the accuracy of hole diameter measurements. We've seen in past columns the importance of operator skill in the use of rocking-type adjustable bore gages, and discussed how variations in part geometry may make even technically accurate measurements inaccurate from a part-function perspective.

One of the fundamental requirements in bore gaging is that the gage contacts be centered in the bore. Bore gages that are not properly centered measure a chord of the circle, rather than its true diameter. Operator error is a common cause of poor centralization with rocking-type gages, while wear or damage can affect the centralization of any gage.

Most adjustable bore gages have a centralizer that helps the operator align the gage properly. Through misuse or wear, a centralizer may be damaged, so that the reference contact is pushed off-center. As long as the centralizer is not loose, it may still be possible to master the damaged gage with a ring gage: the off-center relationship will probably carry over to workpieces, so repeatable results might be obtained. Errors in part geometry, however, could cause a lack of agreement between results from the damaged gage and an undamaged one. And if the damaged gage were to be mastered with gage blocks on a set-master, a different zero reading would be obtained. So in spite of the possibility that an adjustable bore gage with a damaged centralizer might generate accurate results, it cannot be relied upon.

Fixed-size bore gages, such as air tooling and mechanical plugs, are substantially self-centering. They are engineered with a specified clearance between the gage body and a nominal-size bore that is a compromise between ease of insertion on the one hand, and optimum centralization on the other. But after years of use, the plug may become worn, resulting in excessive clearance and poor centralization.

Checking centralization is easy for both gage types. For rocking-type gages, simply compare measurements between a master ring and a set-master of the same nominal dimension. The difference between the round and square surfaces will reveal any lack of centralization. To check a two-contact or two-jet plug, insert the gage horizontally into a master ring, allowing the master to bear the gage's weight. Measure once with the contacts or jets oriented vertically, and once horizontally. If the measurements differ, centralization is poor.

Centralization error is the difference between the true diameter and the length of the chord measured. Quality personnel occasionally specify centralization error as a percentage of the total error budget (or repeatability requirement) for a gaging operation. For example, the error budget might be 10% of the tolerance: in addition to an allowance for centralization error, this might include influences of operator error; gage repeatability; environmental variation; and within-part variation (e.g., geometry error).

Gage users should be prepared to calculate how far off the bore centerline a gage may be without exceeding the specified centralization error. We'll call the allowable distance between the bore centerline and the contact centerline the misalignment tolerance. A simple formula, based on the relationship between the legs and the hypotenuse of a right triangle, does the job:

$$x^2 = z^2 - y^2$$

where:

x = misalignment tolerance
y = z - 1/2 centralization error
z = 1/2 nominal diameter

Let's run through an example. The nominal bore dimension is .5", with a dimensional tolerance of .002" (±.001"). Centralization error is specified at a maximum of 2% of the dimensional tolerance (or .02 x .002" = .00004").

$z = .5" \div 2 = .250"$
$y = .250" - (.00004" \div 2) = .24998"$
$x^2 = (.250")^2 - (.24998")^2$
$x^2 = .0625" - .06249"$
$x^2 = .00001"$
$x = .00316"$

The gage can be misaligned slightly more than .003" off-center before it will exceed the allowable centralization error. If you run through the same exercise for a 5.0" nominal bore, keeping the other values constant, you'll find that misalignment can be up to .010" before centralization error exceeds 2% of the .002" dimensional tolerance. Thus, as bore size increases, so does the misalignment tolerance.

NEVER FORGET THE BASICS

We spend a lot of time in this column discussing sophisticated gages and out-of-the-ordinary applications—so much so, that perhaps we've lately been neglecting the basics. After all, the fanciest electronics, computers and software won't deliver accurate results if good gaging practice is absent. And even old dogs occasionally forget old tricks. So let's review a couple of the bedrock principles that apply to virtually every precision measurement situation: proper gage specification; and inspection, care and maintenance.

First, there's the "ten to one" rule. The measuring instrument should resolve to approximately 1/10 of the tolerance being measured. For example, if the total tolerance spread is .01mm (i.e., ±.005mm), the smallest increment displayed on the gage should be .001mm. A gage that only reads to .005mm can't resolve closely enough for accurate judgments in borderline cases, and doesn't allow for the observation of trends within the tolerance band. On the other hand, a gage that resolves to .0001mm might give the user the impression of excessive part variation, and requires more care to read and record results. It also might not have adequate range, and would certainly cost more than necessary for the application. For some extremely tight tolerance applications (say, ±50 microinches or less), 10:1 is not readily achievable, and it may be necessary to accept 5:1. For coarse work, 10:1, or something very close to it, should always be used.

All measuring tools should be inspected at least once a year for calibration and repeatability. Tools that are used for critical measurements, or that are subjected to unusually hard or frequent use, should be inspected more frequently—possibly as often as every three months. If a gage is dropped, don't take a chance; get it checked right away. Even though it appears to work properly, accuracy or repeatability may have been affected. The cost of having it inspected and calibrated is usually trivial compared to the costs of relying on bad measurements. What may those be? Scrap, rework, returns—possibly even legal liability.

Certification is the process of verifying that a measuring tool meets original-equipment specifications, by checking its performance against a standard that is traceable to a national reference standard. Certification thus represents a higher level of assurance than a normal inspection, which may be performed using gages and standards that are believed to be accurate, but are not themselves certified and traceable. Annual certification of all precision measuring instruments should be a requirement in any shop that prides itself on accurate and/or close-tolerance work, and *must* be done in shops working to achieve or maintain ISO/QS 9000 certification.

Poor gage repeatability has many possible causes, which can generally be summarized as: parts or components that are loose, bent, worn, or sticking. Gage contacts or anvils are probably the most common source of problems, because they're in direct contact with the workpieces, and exposed to damage. They should be visually inspected frequently for chips, scratches, and visible signs of wear, and checked periodically for parallelism and flatness as well. If a chip or dent is detected, that's a good indication that the gage has been dropped, and a signal that you need to have it checked for calibration.

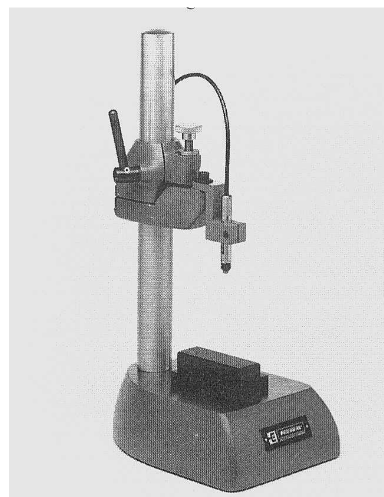
Most handheld measuring instruments are sold with a fitted box. Use it. Don't put loose gages in a toolbox, alongside old drill bits, screwdrivers, and assorted chips and grime. Keep your gages clean, and treat them with care and respect. Any time you see a gage that looks beat up—it probably has been. Don't trust it, unless you first prove its capabilities through inspection, calibration, and certification.

We occasionally see shops that pay their machinists well, and spend hundreds of thousands of dollars on new production equipment, but use old gages, micrometers, and verniers with problems so severe that they won't repeat to within several divisions on the indicator dial or barrel scale. That's penny wise and pound foolish. Regular gage inspection and certification is a clear sign to customers that you take pride in your work, that you're making proper efforts to eliminate bad parts, and that you're seriously committed to quality.

TAKE A STAND

Bench comparators consist of an indicating device, plus a height stand that incorporates a locating surface for the part. (In contrast, a height stand that has no locating surface is known as a test stand, and must be used with a surface plate.) There are hundreds of bench comparator stands on the market, so it's important to understand their features and options.

On some stands—especially those used to measure large parts—the base itself serves as the reference surface. Bases may be either steel or granite, with steel being easier to lap flat when necessary.



For higher accuracy, it is usually desirable to use a comparator stand with a steel or ceramic anvil mounted to the base. As a smaller component, the anvil can be machined to a tighter flatness tolerance than the base—often to a few microinches over its entire surface. In some cases, the anvil may be so flat as to provide a wringing surface for the workpiece—an excellent condition for very critical measurements. The anvil is also easier to keep clean, and can be more readily adjusted to squareness with the indicator.

Some anvils have diagonal grooves milled into the reference surface. These serrations serve to wipe any dirt or chips off the part, and reduce the contact area across which contamination-induced errors may occur.

Accessory positioning devices may be used to increase the comparator's repeatability in various applications. A flat backstop permits lateral exploration of the part for variation, while a vertical vee used as a backstop permits rotational exploration of round parts. A vee can also be mounted horizontally, thus serving as a reference in two directions. Round workpieces may also be held horizontally between a pair of centers attached to the base for runout inspection. A round, horizontal arm may be attached to the post, below the arm that holds the indicator, to serve as a reference for measuring the wall thickness of tubes. And special fixtures may be designed to position odd-shaped parts without a flat bottom. The post is the next important component, where bigger and heavier usually means more stability and less variability. Some posts have spiral grooves to reduce the chance of dirt getting between the post and the arm clamp, which is an invitation to part wear and "slop" in the setup.

The post should provide some kind of arm support beyond the arm's own clamp. Without it, you risk dropping the arm every time you loosen the clamp to adjust the height, which could result in damaged components and crunched fingers. At minimum, there should be a locking ring on the post. A better approach is a rack and pinion drive, which makes it much easier to position the arm, especially if it's a heavy one. Even these should be equipped with their own locking mechanism, so that the weight of the arm does not constantly rest on the drive screw. In some cases, the "post" may be a dovetail slide, which eliminates rotation of the arm in the horizontal plane. This can make setup easier when the anvil remains the same, but the arm must be raised or lowered to measure parts of different lengths.

When it comes to the arm, shorter is better to minimize flexing, although a longer arm may be needed for larger parts. A fine height adjustment screw is a valuable feature for accurate positioning of the indicator relative to the part. Also look for a good locking device that clamps the post to the arm across a broad surface rather than at a single point, as this could allow the arm to pivot up and down. An axial swiveling feature is available with some arms for special positioning needs.

As simple as comparator stands may be, there are hundreds of options, sizes, and levels of quality. Take the time to understand your application thoroughly, and make sure you buy enough capabilities for your needs. You'll end up with faster, easier, more accurate measurements, and less time spent on repairs and adjustments. It may cost more initially, but you'll come out ahead.

PERFECT GAGING IN AN IMPERFECT WORLD

It is certainly not news that, more and more, gages are being forced out onto the shop floor. Tight-tolerance measurements that were once performed in a semi-clean room by a trained inspection technician are now being done right next to the machine, often by the machinist. But just because shop floor gaging has become commonplace, doesn't mean that just any gage can be taken onto the shop floor. To assure good gage performance, there are a number of specifications and care issues which need to be addressed.

Is the gage designed to help the user get good measurements? A gage with good Gage Repeatability and Reproducibility (GR&R) numbers will generate repeatable measurements for anyone who's trained to use it properly. Technique or "feel" should have minimal impact on results.

Gages with good GR&R are typically very robust. Part alignment is designed in, to make sure the part is held the same way every time and eliminate the effects of operator influence on part positioning. Bench gages usually outperform handheld gages in both respects.

Is the gage designed for the rigors of the shop floor environment? Gages designed for laboratory use often cannot cope with the dust and oil present on the shop floor. Some features commonly found on good shop floor gages include: careful sealing or shielding against contaminants; smooth surfaces without nooks and crannies that are difficult to clean; and sloping surfaces or overhangs designed to direct dust and fluids away from the display. (Try to distinguish between swoopy-looking cabinets that just look good, and those that are truly functional.) If all of these are absent, one can often add years to a gage's useful life by installing it in a simple Lexan enclosure with a hinged door, or even by protecting it with a simple vinyl cover when it's not in use.

Is the gage easy to operate? Machinists like gages that operate like their CNC machines; once it's been programmed, you push a button, and the machine runs, cuts a feature, and is ready for the next part. Gaging should be simple too, requiring as few steps as possible to generate results. If a variety of parts are to be measured on the same gage, it should allow for quick, easy changeovers. Electronic gaging amplifiers, computer-controlled gages (such as surface finish and geometry gages), and even some digital indicators are programmable, so that the user only has to select the proper program and push a button in order to perform the measurements appropriate to a particular part.

No matter how well protected it is against contamination, if a gage is used on dirty parts, or in a dirty environment, it will get dirty. At the end of every shift, wipe down the master and place it in its storage box. Wipe down the gage, and inspect it for loose parts: contacts, reference surfaces, locking knobs, posts, arms, etc. Do this every day, and you will probably prolong its life by years or at least, you'll make it easier for the calibration department to check it out and verify its operation.

Pretend for a moment that you've just installed a new planer in your basement woodshop. Glowing with pride, you set it up, adjust it, and then, just for fun, you make a big pile of shavings. And next? I'll bet you clean it off carefully, maybe oil the iron posts, and promise yourself that you'll always follow the recommended maintenance procedures.

Not a woodworker? Then you probably treat your golf clubs, boat, Harley, or flower-arranging equipment with the same pride of ownership. So why not your gages, which are far more precise than any of these, and deserve far more attention.

TIRED OF BICKERING OVER PART SPECS? STANDARDIZE THE MEASUREMENT PROCESS

How many times have you heard an assembly operation complain that incoming parts are consistently out of spec? How many times have you heard the parts people trash assembly folks for not knowing how to use their measurement tools? They were shipped good parts and now they measure bad. What's going on here? Where is the problem?

During the manufacturing cycle for a part or product, many people will look at the part to determine whether it meets the specification. Typically, these could include the machinist producing the part, a QC person, an incoming inspector at the company using the part, and finally another inspector who may be responsible for evaluating the manufactured part's performance within an assembly.

With this many inspection processes, it's very unlikely that they will all be similar, let alone use the same gaging equipment. Even if skilled craftsmen at each inspection point follow their particular measurement processes to the letter, there will, at times, be unsettling disparities in measurement results.

Let's look at a very simple part, a cylinder 1" long x 5" diameter having a tolerance of

±0.0005". How many ways could we measure this part? Here are some of the most popular: micrometer, digital caliper, snap gage, bench stand with anvil and dial indicator, air fork, light curtain, optical comparator, special fixture w/two opposing gage heads and electronic amplifier or, even, a vee with a digital indicator.

Add just a little form or surface finish variation in the part and it's very likely that each one of these inspection systems mentioned above would produce a different result. Even with gages in top condition, there will be slight, if not major, differences. Simply the type of gaging being used and how they contact the part may cause this.

Suppose one company is using an air gage to measure the roundness of a part and another company is using a snap gage. In addition, let's suppose that the part has a very coarse surface finish greater than 50 RA. In this case there will rarely be a correlation between measurement results. This is because the air jet tends to average the peaks and valleys in the finish, while the hard contacts of the snap gage will ride on the peaks. This situation is a disagreement waiting to happen.

What if one company is using a two-point contact gage and the other is using a gage with three contact points? Will the results be comparable? Not if the part has an odd number of lobes. It is an interesting quirk of geometry that a two-contact point gage, as it is rotated around an odd-lobed part will always see the parts diameter. Another disparity between inspection systems is about to happen. On the other hand if a part has an even number of lobes, both gages will deliver comparable results.

One more: What if the part isn't quite straight and one inspector measures with two direct contact points and the other uses a snap gage which makes two "line" contacts with the part? As you rotate the contact point gage, it follows accurately around the part's diameter but the line contact tool will interpret the part's out-of-straightness as out-of-roundness.

There are certainly dozens, if not hundreds, of variations on this theme, but you should get the point by now. While a variety of tools may be used to measure a given dimension, a disparity in measurement processes up- and downstream from your inspection point will, sooner or later, cause unneeded rejection and delays in the acceptance of the part.

If this tune is all too familiar and you don't want to hear it any more, get together with your suppliers and customers and standardize your measurement tools and processes particularly for critical dimensions. It may seem like a little extra work, but in the long run, everybody will benefit.

STARTING FROM ZERO

Writing '00 instead of '99 reminds me of the importance of zeroing out the measuring instrument or gage before starting to make a measurement. Zeroing sets a reference point from which all subsequent measurements are made. If a gage has been allowed to drift from zero, it will introduce error into the measurement process. So it's important to "Think Zero," and think it often.

Why do gages shift their zero point? There are probably as many reasons as there are types of gages. But the top reasons include: wear, temperature effects, loose gaging components and dirt. It's important to check zero as often as needed, so that you feel comfortable with the measurement process.

Basic instruments like micrometers or calipers use their scales as the reference. With a vernier micrometer, verifying the reference point is straightforward. Close the contacts together and read the vernier scale. The scale should indicate zero. If it doesn't, you can be sure that every measurement from then on is going to be off by the amount indicated on the scale.

There are two things you can do to correct the problem. The lazy man's way out is to add or subtract this offset with every measurement. This is a trap that may cause a lot of grief the first time you forget to apply the offset.

The best thing to do is correct this disaster waiting to happen by adjusting the micrometer to make it read zero with the contacts closed. Most micrometers, both friction and ratchet drive types, provide instructions to adjust this zero point. Follow the instructions carefully and you will have your micrometer zeroed out in a matter of minutes.

Similarly, a vernier or dial caliper can be checked by bringing the contacts together and holding the jaws up to a light. You should not see light passing through the jaw surfaces. Look for gaps or taper conditions that indicate a worn jaw. If the jaw passes inspection, check for the zero readings. On a vernier caliper you will need to read the lines, while on a dial caliper the indicator should read zero. Both can be adjusted to read zero.

Digital hand tools are easy to zero. Close the jaws and press the zero button. That's all there is to it. The instrument does this important little task electronically.

Comparison type measurement hand tools such as snap gages, gage stands, bore gages, etc., may be a little trickier, but they also need to be zeroed regularly. The process is slightly different, but the end result is the same. With this type of gage the zero point is actually a reference dimension to which dimensions on the parts will be compared. An ID, for example, will be shown to be greater or less than the zero (reference dimension).

For dial indicators, the method is to mechanically adjust the dial indicator on the master so that it is in its midrange, and lock it firmly into place. Then loosen the bezel clamp and turn the dial so that the indicator hand lines up with the zero on the dial.

Something else to remember is that setting to zero this once does not end the process. Take the master out and replace it a number of times in the gage, and check for zero again. A bit of dirt may have been introduced in the initial setting and repeating the process a number of times will help instill confidence in the set-up. Usually you want to have a dial indicator reading repeat its zero setting to within a half of a grad or so, or a digital readout should be to within one count. This varies a little depending on the gage and the resolution, but in any case we are assuming that the gage has already been checked for repeatability performance.

You should also know that there are instances where you may want to set your gage to a value other than zero. This makes it possible to correct for a known error in the master or to use a different size master for measuring the part. For example, if the master is +.0002" larger than the nominal dimension for the part, you would set the dial on the indicator to +.0002" instead of zero. Now if you have a perfect part, the gage would read 0.0" when the part is measured. Electronic dial indicators and amplifiers, in addition to zeroing buttons, usually have master deviation functions to do the same type of correction.

Zeroing the gage is the very foundation of good measurement practice, but we know from experience that most gages are not zeroed often enough. If too many measurements have been made or too much time has elapsed since the gage has been zeroed, measurements will all be biased by zero shift. An extreme solution would be to zero, measure, and zero for every part. This would be overdoing it in most cases. On the other hand, zeroing once a day is probably too little. Generally speaking, once an hour is just about right, but the application itself should dictate the zeroing frequency.

IT DON'T MEAN A THING IF IT'S GOT THAT SPRING
Or What To Do When Your Fixture Isn't as Fixed as You Thought

Believe it or not, one of the most overlooked problems in qualifying gages is unaccounted for deflection of the fixture due to the force of the probe on the part. Who would have guessed? After all, fixtures are used to provide stability.

Most fixtures are made of several component parts, and are, in essence, a variation of the well-known C-frame. If the user is aware of some common problems that can affect the use of the C-frame and other fixture designs, he can quite easily detect and eliminate possible error sources like deflection.

All materials, regardless of their hardness, have some degree of elasticity. That also applies to the frames we use to fixture our parts for gaging. Small as it may be, this elasticity is a real and vital consideration in a precision gaging setup. Even the slightest pressures will cause some deflection of the frame. If the deflection is great enough, it will throw off the calibrated accuracy of the gage.

There are several possible solutions. You can: (1) increase the spring rate (i.e., stiffness) of the gage frame to the point where deflection is no longer great enough to affect calibration; or (2) reduce the spring rate of the indicating system until the deflection of the frame becomes insignificant in comparison; or, lastly, (3) compensate for the deflection. While it is possible to compensate for deflection with a reasonable degree of accuracy, your best bet is to take the problem completely out of play with one of the first two choices.

The tendency for an object to deflect is known as the "spring rate." It is the ratio of the load applied to the fixture component (expressed in pounds) to the resulting deflection (expressed in inches). So the higher the spring rate, the less the frame will deflect under a given load. The size of the part to be gaged also figures heavily in whether or not spring rate will be a large or small problem. Large frames designed to accommodate sizeable workpieces are much more susceptible to error caused by frame deflection than are the ones for small pieces. It's a matter of leverage.

As a rule of thumb, the spring rate of the fixture should be at least 100 times greater than the spring rate of the indicator. Fortunately, there is an easy way to test this without doing a lot of math. With a workpiece in your gaging system and the indicator on zero, place a known weight (e.g., one pound) on the arm of the frame at the center line of the indicator's spindle. The deflection of the frame will be shown on the indicator of the gage. Let's say, for example, the deflection is .004". By applying the 100:1 rule, we know that the load on our probe to make a .004" measurement should not exceed about 100th of a pound or approximately 4.5 grams. Otherwise, deflection of the fixture may alter the result unacceptably.

Next, we find out how much load it actually takes to move our gage .004" during measurement. If you haven't removed the one pound weight, do that. Using a dynamometer, place the lever underneath the contact point of the measuring indicator (dial indicator, electronic probe, etc.). Zero out the indicator and then using the dynamometer apply pressure to the contact until you make the indicator move to 0.004" and note the reading on the dynamometer. If the force is less then 4.5 grams then you're home free.

If the ratio is smaller than 100:1, try making the fixture more rigid or reducing the gaging force of the indicator by going to a lighter force spring. As a last resort, you can introduce a compensation factor to all indicator readings. For example, if the spring rate ratio of the fixture to the gage is as low as ten to one, you may try multiplying the indicator reading by approximately 110% to approximate the proper answer.

This added 10% will compensate for the fact that one out of every ten units of part dimension away from zero or nominal results in the spring force of the indicator deflecting the frame arrangement rather than moving the indicator mechanism. It should be understood that this formula for an acceptable spring rate ratio applies only to comparative gaging, i.e., gaging in which the instrument was initially zeroed with a master of the same size as the part to be checked. Spring rates do change with displacement. Also, this process also assumes that there is no part deflection as a result of the measuring forces.

The concept is more difficult to explain than it is to test for. Work through the steps for one gaging setup and you will have mastered a valuable skill to use whenever you suspect that fixture deflection may be causing a problem.

WHAT GOOD IS A PARALLELOGRAM? The ABCs of Reed Spring Motion Transfer

Do you remember learning the names of weird shapes in elementary school and then later in geometry? There were isosceles triangles, parallelograms, dodecahedrons. What good would come of all this bizarre knowledge in "real life?"

Well, it turns out that at least one of these shapes is very important to those of us who lay out gaging setups or select precision measurement tools. It's the parallelogram and it can make high-precision measurements very repeatable and save a lot of money by minimizing wear and tear on expensive sensors. But before we get to the benefits, we have to talk a little bit about theprinciples involved.

A parallelogram has four straight sides. The two pairs of opposing sides are of equal length and are parallel. The unique properties of the parallelogram have been applied extensively in industry to accurately transfer mechanical motion from one place to another. Perhaps the best known application is the pantograph, a four-sided device used frequently by engravers to reproduce an image outline to a user-definable scale, either smaller or larger.

In gages and gaging setups, simple devices called "reed springs" simulate the behavior of parallelograms to transfer motion from one component to another. One type of reed spring consists of two parallel blocks connected by two or more steel connecting strips of equal size and stiffness to form a reed-type flexure linkage. One of the blocks is attached to a fixed surface When a force is applied to the free block, the connection strips flex, resulting in a displacement of the movable block.

Some observers will note that when this movement occurs, the connecting strips bend ever so slightly and that, technically speaking, the parallelogram has been compromised. However, I'm sure you would not be such a nitpicker. What is important is that fixed and moving blocks are still parallel and that the moving block is not deformed by the contact. So nothing has been added or subtracted to the degree of motion transferred. For high precision transfer of motion involving a range of a few thousandths, reed springs can be "EDM'd" from a solid piece of steel.

So now that we've gone through all this, what's the big deal? If you don't care about damage to your sensor and on-going repeatability, then you can use a simple height stand and sensor, and allow for one part after another to be continually slammed underneath it. Or you can transfer the motion inside the gage in a way that protects the sensor and ensures repeatability.

Here are how reed springs can be used for this purpose:

A. In a gaging situation where it may be necessary to protect the gaging indicator, the reed will accept all the side loading and not transfer it to the sensor. So the reed switch itself takes all the pounding rather than the expensive sensor. This is a simple linear application anyone might use.

B. Reed springs may also be used in gaging in situations where the contact point and sensor must be in different locations. Again, the reed absorbs the side loading as it allows for placement of contact at locations where the sensor may not fit, in this case a confined inside diameter.

C. Finally, the reed spring can be manufactured into a micro precision sensor itself. The reed spring protects the valuable sensor while its accurate frictionless motion results in an extremely accurate and repeatable micro inch measurement.

Are there other ways to do the same things? Certainly. Precision bearings and slides come immediately to mind. However, the reed spring is unique in that it is less expensive and there is no moving contact between its components. This latter quality practically defies the laws of physics by resisting the onslaught of dirt and grease, and being frictionless, the reed can sustain virtually millions of cycles without any noticeable damage. Perfect, in other words, for harsh, shop floor environments. The only downside is its limited degree of motion. But we are talking about precision measurement here.

So now you know what parallelograms are good for. I am glad to be the bearer of the good news that at least a small part of your early education has not gone to waste. Now, do your part. If anyone out there has come across a practical application of the dodecahedron, I would like to know about it.

GAGING OLDIES BUT GOODIES—
A REVIEW OF SOME THINGS WE SHOULD KNOW BY NOW

In Honor of this Column's Tenth Anniversary

Ten years ago this month, "Quality Gaging Tips" first appeared in **Modern Machine Shop**. Since that time, we have covered many tools and techniques for assuring accurate, repeatable measurement and gaging in machine shops. So I thought it would be appropriate to double back and talk about some oldies but goodies—things we should know all too well by now, but sometimes overlook or take for granted. Here are a few of my personal favorites:

10:1 Rule. Whenever possible, the measuring instrument should resolve to approximately one-tenth of the tolerance being measured. So if the total tolerance spread is 0.01 mm (that is, ±0.005 mm), the smallest increment displayed on the gage should be 0.001 mm. This amount of resolution allows you to make accurate judgments for borderline cases and makes it possible to observe trends within the tolerance band. Many people know of and can explain this rule. Yet it can still sneak up on the best of us and bite us in the leg with appalling frequency.

Simple SPC. It's amazing how many shops still don't do SPC because they can't afford digital gaging equipment, don't have the right computers or software—name your favorite excuse. One of the first SPC manuals was published by Federal Products in 1945, long before the digital revolution. It has gone through 14 printings. Back then, simple SPC empowered machine operators to keep their processes in control by showing them how to make simple charts and other visuals that gave them regular feedback on how things were going.

SPC wasn't conceived of as something you have to buy, but something easy you can do. SPC can be that simple, or it can be very complex. By starting out on the simple side and taking just one step at a time, any shop can develop an SPC program to take it to the next level of manufacturing excellence. The trick is to get started. Later on, you can think about getting digital tools, more computers and software.

SWIPE. When gaging results don't live up to expectations, it's easy to blame the gage. However, this outlook will rarely get you on the right track. A more helpful approach is to consider how good gaging practice encompasses a range of factors which can be summarized by a single acronym, SWIPE. The letters represent Standard, Workpiece, Instrument, Personnel and Environment. Study how each of these might contribute to the effective or ineffective use of gaging and you will be on the shortest path to setting up a solid gaging system or troubleshooting one that is currently shaky.

How to Use a Rule. It is impossible to overemphasize how important it is to remember the basics. For example, one of the oldest and most pervasive of all measurement tools is the steel rule. But when was the last time you received any training in how to use it? The first grade?

“What’s there to know?” you ask. Plenty. Rule styles, for example: English or metric, rules with the zero point on the edge or inset a short way. Avoiding parralax error. Using a stop, even if it’s your thumb, for better alignment. Better still, starting a measurement at a graduation instead of the edge. Measuring similar parts from the same starting point and in the same direction for greater consistency. The fine art of rotating the rule to get the longest dimension
(e.g., diameter) across a hole. Finally, when you need to use a more accurate measuring tool (See 10:1 rule above). If basic skills are so important to using something as mundane as a rule, imagine the influence they have on something more complex like calipers, a CMM or laser interferometer.

The truth is that no matter how technologically advanced our manufacturing processes have become, we will never outgrow our need for revisiting basic measurement. From the
pyramids to the space station, they continue to be the foundation upon which anything of quality was ever built.

WHERE'S THE FAULT? SWIPE To Find Out

Nobody likes to be the bearer of bad tidings. This goes back to the dawn of recorded history, when a tribal leader might easily decide to kill the messenger if the news was not to his liking. A modern-day version is to blame your gaging equipment supplier when your quality assurance measurements are not measuring up to expectation.

If you are sure the parts are good, but the measurements are inconsistent or just plain wrong, or if bad parts are getting past your inspection system, the problem could very well be the gage itself. Since the gage is the messenger, it's the obvious place to start, but not necessarily the most logical. Gaging equipment manufacturers should have a good handle on what it takes to control their manufacturing processes to deliver consistent quality.

The better thing to do is step back and look at your measurement system as a whole. It consists of five elements which can be summarized by a single acronym, SWIPE. It stands for Standard, Workpiece, Instrument, People and Environment. SWIPE is a handy template to follow, both for initially setting up a manufacturing process and for getting to the source of any measurement problem should one materialize.

Standard

In gaging, a comparative measurement is obtained by comparing workpiece dimensions to established physical standards. These include gage blocks, as well as master discs and rings. These standards must be routinely calibrated to ensure that they are even more accurate than the gages they are used to master. These standards should be handled as carefully as gage blocks, because nicks and scratches can be a significant contributor to error.

Workpiece

The measurement process must be appropriate to the workpiece. For example, centerless grinding often imposes a slight three-lobed condition on round parts. Most gages aren't designed to detect this condition and will register the part's average diameter rather than its effective maximum diameter.

What's more, it is dangerous to assume that just because a part feature falls within specified dimensions at one point, it will at all others. No part surface is perfectly round, flat or smooth. When a production process is under control, the amount of variation in roundness, flatness, etc. is small enough so all points on the part surface fall within the specified tolerances. If the process is out of control, some points may lie outside of tolerances even though the gage indicates that the specific point being measured is in tolerance.

Instrument

In addition to being suitable for the specific workpiece, the gage must be in good condition, properly mastered, and capable of holding calibration throughout a reasonable service period. Another thing to think about is how your customer might be measuring the part at the receiving end. You may check bores with an air gage and your customer with a mechanical gage. The air gage averages peaks and valleys while the mechanical gage only measures peaks. Neither gage is "wrong," but the results are not comparable either. This is where friendly or unfriendly disagreements occur.

People

Obtaining consistently good (i.e., accurate and repeatable) measurement results is also a people issue. Have they been adequately trained to operate the measurement system and record the results? Are the operators assuming responsibility for proper gage care and maintenance? Checking for looseness, parallelism, nicks and scratches, dirt, rust, and so on, is absolutely necessary to ensure system performance. It is only natural to cut corners if you are under pressure. It is also natural, perhaps even inevitable, for corner-cutting to result in a faulty measurement system.

Environment

Several factors in the environment around the gage must be considered. First there is dirt, dust and grease, the leading enemies of consistent, accurate gaging. Then there may be thermal influences from heating/air-conditioning systems, drafts, direct sunlight, nearby machines, a hot workpiece and even the operator's body heat. What about static electricity, magnetism, power surges, RFI/EMI and external movement which may be obvious as vibrations from a nearby stamping press or as subtle as the tide rising and falling in a river several blocks away from the plant?

So before you kill the messenger, take a complete SWIPE at your total measurement system. Then, if you've done a careful and thorough SWIPE review and still can't find the problem, call your gaging equipment vendor. Let him have it.

COMING TO TERMS WITH ACCURACY

A question I am frequently asked, by very sincere people to be sure, is, "How accurate is that gage?" I am usually tempted to say something like, "Super accurate" or "So accurate you wouldn't believe it!" But I don't. Instead, I take a deep breath and give my questioner a couple paragraphs-worth of information, then watch his jaw drop because he was only expecting a few words.

It just can't be helped. Accuracy is not a simple subject. You have to come at it from several directions before you can nail it down. To have a meaningful conversation with a metrologist or gage supplier about accuracy, without being bamboozled, you have to understand some basic terms that relate to the concept of accuracy. Here's a crash course.

Accuracy. This murky little term deals with several characteristics of gage performance. One of the best definitions of accuracy I know is "the relationship of the workpiece's real dimensions to what the gage actually says." It's not a quantifiable definition, but it does provide a framework for some of the following characteristics, which are.

Repeatability. This is the ability of a gage or gaging system to produce the same reading every time the same dimension is measured. A gage can be extremely repeatable and still highly inaccurate. A gage with poor repeatability will, on occasion, produce an accurate reading, but it is of little value because you never know when it is right.

Stability. Closely related to precision, stability refers to a gage's consistency over time. The gage may have good precision for the first 15 uses, but how about the first 150? All gages are subject to sources of long-term wear and degradation.

Resolution. Resolution is the degree to which the analog scale of an indicating device permits the user to distinguish meaningfully between adjacent graduations of the quantity indicated. A machinist can generally estimate the pointer's position between two graduations on a dial, but usually not to the resolution of the nearest tenth of a graduation. To prevent users from making guesstimations between the lines, it is generally advisable to select gages that discriminate to a finer level than the measurement units required by the application. Measurements are generally considered reliable only to the level of plus or minus one unit of discrimination. So, for example, if measurements to .001 inch are required, the indicator should discriminate to .0005 inch or better.

For a digital gage, the resolution is the change in the indication when the digit farthest to the right of the decimal point changes one step.

Magnification. Magnification is generally defined as the ratio of the length of the display scale to the amount of displacement actually seen by the gage. Today, it is used in reference to the performance of optics equipment, such as microscopes. The current preferred term in metrology is amplification.

Amplification. In dimensional metrology this can be thought of as getting more than you've got. In a dial indicator, for example, gears or levers amplify the plunger movement. In the electronic world, amplifiers provide output of greater magnitude. But beware.

Amplification can create the illusion of accuracy while simultaneously 'magnifying' sources of error.

Measurement Range. Measurement range is the distance over which measurements may be taken. With analog gage designs, measurement ranges tend to decrease as amplification increases.

Hysteresis. In gaging, hysteresis is the error which occurs when a measuring instrument gives different readings for the same dimension when measured in opposite directions. Often with dial indicators, it is a component of bi-directional repeatability caused by clearance (backlash) of the gear train.

Calibration. Calibration refers to how closely measurements made by a gage correspond to the dimensions of known standards throughout its entire measuring range. A gage with good precision may be usable even if its calibration is off, as long as a correction factor is used.

Understand the terms defined above and, should you ever be so bold as to ask a metrologist about the accuracy of his gage, you will be prepared for the answer. One more word to the wise: only ask him if you really want to know.

FEELS LIKE A GO TO ME

Once upon a time, an overly enthusiastic QC manager appealed to me, confused and dissatisfied. Here he was, spending good money to purchase very high quality masters, but his inspection process was no better than before. What was worse, his masters went out of calibration rapidly, pushing his costs even higher. The problem was that he was buying more accuracy than he could use.

Choosing the right tool for the job applies to mastering, just as it applies to every other area of gaging. While it may be possible to master a gage using a variety of standards, the best master for a job strikes a balance between accuracy, economy, durability, and ease of use.

Gage blocks are "primary standards," directly traceable to an "absolute" standard maintained by NIST, DIN, or ISO. Masters are "secondary" standards, because their sizes are established by reference to primary standards. While masters typically have a higher level of uncertainty than gage blocks, they are often the appropriate choice for production gaging. Gage blocks, after all, are square, while masters are typically round. If the parts being measured are round, and the gage is designed to measure round parts, the use of a round master will help avoid certain sources of geometry error.

A master ring or ring gage is basically a bore of a known dimension. The same device can often be used as a setting master for variable inside-diameter gages (such as bore gages, air tooling, and mechanical plug gages), for go/no-go mastering of fixed ID gages (such as a fixed plug gage), and for go/no-go OD inspection of male cylindrical workpieces.

Ring gages are made from steel, chromed steel for durability and corrosion resistance, or tungsten carbide for extreme wear resistance. They are classed by level of accuracy, with XXX indicating the tightest tolerances, XX, X, and Y being intermediate grades (in descending order), and Z being the lowest level of accuracy. Class tolerances vary by size: larger sizes have higher levels of uncertainty. Tolerances may be bilateral (i.e., evenly split between plus and minus around the nominal dimension), for use in setting variable gages, or unilateral for use as go/no-go gages. For rings, "go" is minus (-); for plugs, "go" is plus (+). Go/no-go gages may often be identified by a groove or ring on their knurled outside diameters.

Plug gages, for go/no-go measurements of part IDs, or for mastering ID gages, are also available in different materials and classes. Plug gages may be reversible or double ended, with a "go" end signified by a green stripe, and a "no go" end signified by a red stripe. Usually available only in sizes up to about 0.76", reversible plug gages can be disassembled to replace a worn end.

Plug gages are often identified by the names of their handle or mounting designs. Taper-lock plug gages usually range from 0.059" to 1.510", and have a handle on only one end. Tri-lock designs, also called discs, range from 1.510" to 8.010", and have handles on both ends of the mastering surface. Annular designs, for sizes from 8.010" to 12.010", are like wagon wheels, with handles for axles.

Specialty masters are available for a range of applications and odd shapes, including slots, splines, and tapers. Tool holder taper geometry is of increasing importance in precision machining, and manufacturers have begun to pay closer attention to taper quality. Taper plug gages can provide an indication of whether an ID taper is too steep or too shallow, or if the bore entry diameter is within tolerances. Inside and outside taper masters are also frequently used for setting taper air gaging. Such special-purpose masters make mastering and measuring quicker and easier, and usually cost more than standard gages.

In general, one should choose a master whose tolerance is 10 percent of the precision of the gage, while the gage's precision and repeatability should be 10% of the part tolerance. For example, if part tolerance is 0.001", gage precision should be 0.0001", and the master's tolerance should be 0.000010". It's usually not worthwhile to buy more accuracy than this "ten to one" rule: it costs more, it doesn't improve the accuracy of the gage, and the master will lose calibration faster. On the other hand, when manufacturing to extremely tight tolerances, a ratio of 4:1 or even 3:1 between gage and standard might have to be accepted.

Finally, here are some general guidelines for the care and feeding of masters: store them in a secure place; use a wax- or oil-based sealant to protect against corrosion; handle carefully—don't force or jam them onto the part; don't try to modify them; and when shipping for calibration, take steps to protect masters against damage and corrosion.

SAY HELLO TO MR. ABBÉ, MR. HOOKE, AND MR. HERTZ
(ALTHOUGH YOU'VE PROBABLY MET THEM BEFORE)

Whenever you use a handtool or precision gage, you should be aware of typical pitfalls that prevent good gage performance. These include measurement errors resulting from environmental conditions (dirt & temperature), loose and/or worn gage parts, along with operator misuse. But there are other gaging pitfalls lying in wait which must be considered, both as part of good gage design and good measuring procedure. These issues become particularly important as the need for gage performance increases. They are typified by our three friends, Mr. Abbé, Mr. Hooke, and Mr. Hertz, and most likely sit with you while you are performing your gaging process. Let me introduce you.

Meet Mr. Abbé, a noted optical designer. His principle states: maximum accuracy may be obtained when the reference scale and the workpiece being measured are aligned in the same measurement. This is the case when using a standard set of micrometers: the measuring scale, (i.e., the micrometer barrel or digital scale) is in line with the part and the reference contact. However, in the case of a caliper gage, this is not true.

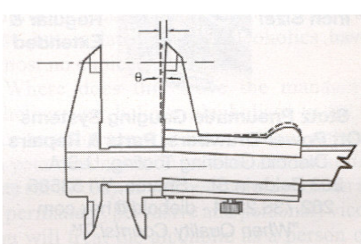


Fig. 1

With this type of gage, the measuring scale is below the contacts, and if there is any angular moment to the jaws during measurement, Mr. Abbé says hello (fig. 1).

Another type of gage where the measurement scale has often not been in line with the part is the horizontal length machine. Notice that on many of today's newly designed horizontal length measuring machines, great effort has been made to place the scale either in line or as close to the measuring line as possible.

Also, say hello to Mr. Hooke, a physicist who determined that the amount a spring stretches varies directly with the amount of force applied to it. Now, you may say there are no springs in my micrometer, but in reality, the frame of the gage actually acts like a spring. Since springs are sometimes made of steel, steel gaging frames can act like springs. Whenever you turn the barrel of a micrometer down onto the part (fig. 2), you are applying force to the part and the reference contact. There is some "spring" action taking place in the frame. This is one of the reasons, as we noted previously, for the friction or ratchet drive used in the micrometer barrel. By employing a constant measuring force, we always incorporate the same "spring" of the frame into our measurement, and improve repeatability. This ratchet in the micrometer is a reminder that Mr. Hooke is still around.

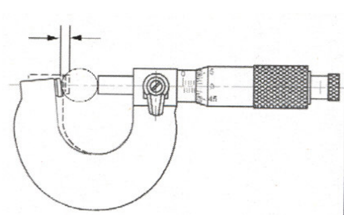


Fig. 2

And finally, we welcome Mr. Hertz, another physicist who developed a formula that determines the amount of surface deformation within a material's elastic limit (remember the springy steel) when two surfaces are pressed against each other under a certain force (fig. 3).

There are formulas for cylindrical, spherical, and planar surfaces. These formulas are important for determining the deformation of a workpiece caused by the measuring force. The results determined by these formulas are typically small when working with steel, but these small umbers turn out to be important in gage block measurement. They also need to be considered when dealing with compressible materials.

For example, let's say we have a 0.125" radius diamond contact applying a gaging pressure of 6.4 ounces on a gage block. With a steel gage block, penetration would be approximately 10μ". However with a carbide gage block it would be about 6.6μ". Pretty small stuff—but in the gage block world, the difference can be a major portion of the block's tolerance. And if you know about it, you can deal with it.

In short, when all three of these guys get together and put their forces to work, it's party time! Understanding their principles, and planning for their presence, keeps them under control.

A DIFFERENT DIFFERENTIAL

When we talk about differential gaging, we are usually referring to the process of using two sensing devices and combining the results into one measurement. The measured dimension is the change in the position of the two sensing components.

We've talked before about why differential gaging has some advantages over normal, comparative measurements using a single sensing head against a fixed reference surface. These include the measurement of size without regard to position (see Figure 1). When the two gage heads are in line and in an opposed position, the sensed dimension will be the change in the separation of the two gage tips: in this case, the size of the part.

When we measure in this manner, the staging of the part does not become part of the measurement loop. The platen in a differential system just places the part between transducers. With a single head system, the platen is part of the measurement loop, and therefore flatness and configuration of the platen is critical.

There are available a number of different measuring systems that can provide differential gaging, including air and electronic gaging. Air gaging is probably the most common, since every two-jet air plug and air ring utilizes the differential gaging principle. Most air gages measure back-pressure that builds up in the system when the tooling is placed in close proximity to a work-piece: this results in higher air pressure, which the gage comparator converts into a dimensional value. Thus, as the plug fits into the part, it is the combination of both jets that represents the diameter of the part—without regard to where in the part the plug happens to be.

The same is true with electronic probes. In this case though, the probes are combined electronically to provide the differential measurement. Differential gaging using both air and electronic probes is used in a wide variety of applications that include measurement of form on angles and tapers and shafts without regard to the part dimensions. Also, concentricity of two shaft diameters, comparing a work-piece to a master, match gaging, and finally, checking parallelism of a work-piece and its support surface are all applications of this technique.

However, there is another form of differential measurement that is probably not used as often as it could be. This is a mechanical method that provides the same results as air or electronic gage-based differential measurement, but it requires only a single sensing head. It's accomplished by providing a means for the body of the indicator, which becomes the second sensing head, to move along with independent movement of the contact itself. Since the system uses only one sensing head, it can provide very high performance in a space much smaller than when two sensing heads are required.

Figure 2 shows an example of a simulation of a mechanical differential check. In this case we are simulating the measurement of a ball, but it could very well be any other type of length measurement. The method uses friction-free panto-transfer units, but they could very well be any high precision ball slide. By looking at the figure we can see that if we held panto "A" fixed and moved panto "B", the stem of the indicator would move and the amount would be shown on the indicator. On the other hand if panto "B" was held fixed and "A" was allowed to move, the rack of the indicator would be the sensing portion and the motion would also be shown on the indicator.Once both are allowed to move, the combination of both panto transfer units make up the differential measurement, without regard to where the part is located within the range of the measurement heads.

Making use of this simple, but effective method can produce equal and sometimes superior results. This technique can be very handy in situations where there are space limitations and two transducers don't fit into the gaging station.

ANOTHER WAY TO SQUARE IT UP, OR IS IT 'PERPENDICULAR' IT UP?

There are a number of tools available for shop personnel to evaluate the right angle relationship between two surfaces.

The basic machinist square has a number of variations, the most common being the hardened steel square. It is used to check right angles and set up milling and drilling machines. The hardened steel square consists of a thin blade and a thick beam that are set at precise right angles to each other. The square has no scales and is not useful for linear measurements. To evaluate the right angle, the user holds the thick beam on the reference surface and the blade against the side of the part, then looks for light between the blade and the part, or slips feeler stock between the two. These types of squares are usually used on work where tolerances of 0.001" are called out.

The funny thing about these so-called "squares" is that they are not squares, and are actually used to check the right angle relationship between the two surfaces, also known as perpendicularity. Most prints have a call-out requiring a right angle relationship, but one right angle does not make a square. There may also be a call-out for a part to be square, but this refers to the geometric shape of the part. It may be that the reason for calling this simple tool a "square" is that it's too difficult to say, "Hand me that perpendicular." But since this is the language used around the shop, we can keep talking about inspecting for the right angle as a squareness check.

A cylindrical square can be used in a manner similar to the machinist square. By placing the cylinder next to the part and using the same visual or feeler stock check, the operator can get a very good sense of right angle.

There are also a number of other hand tools used to inspect for the square form in a part, including combination squares, linear and digital protractors, and even electronic levels. But if parts are over 8" in length, hand tools cannot cover the range needed and surface plate tools are required. In addition, hand tool methods all rely on the observation and skill of the operator to interpret the angle. None of them provide any empirical data that can be analyzed or used to begin controlling the process.

For large part/surface plate work, one of the best means to inspect for squareness is to use the precise vertical ways that are built into a height gage or master squareness gage. Both of these gages have a precision slide to which a dial or test indicator can be mounted. This allows the indicator to be moved in an accurate, vertical line of travel when both the gage and part are on the surface plate. The advantage of this type of squareness gage over handheld, visual squares is that the dial test indicator allows the operator to read the exact amount of error instead of judging it by eye.

Since both the master squareness and height gages use the same reference surface as the part (i.e., the surface plate), and as the gages themselves provide a precise reference for the vertical axis, both are capable of measuring the perpendicularity of the side compared to the base. On the downside, master squareness gages are not capable of measuring the horizontal axis of the part, and in neither case are the vertical and horizontal readings tied together, so the user has to plot the individual values to come up with a measurement. But if you are really interested in data collection, you'll want to use a motorized electronic height gage. These gages not only allow automated positioning, but also have the capability of using a high-resolution linear encoder for positioning the indicator along the vertical axis, and a similar linear scale for the horizontal axis. Most electronic height gages have dedicated, preprogrammed functions for checking perpendicularity. All the operator needs to do is enter the length of the path to be inspected and the number of readings to be taken along that path. The slide can be positioned manually along the path (as with the master squareness gage) to let the gage controller collect the data, or the gage can execute an automated data measurement routine.

Once the measurement cycle is completed, the processor can provide the actual angle measured, the full table of the test part, or even a graph of the part profile. This can be invaluable for large parts where lapping can be performed to fix demonstrated high or low spots. As with any surface plate work, the plate is the reference for both the part and the height gage, therefore a clean plate and a high degree of flatness are essential when making precision checks.

In sum, with the handheld, machinist square measurements, operator influence and visual techniques limit the process to 0.001" tolerance levels. Height gages with high performance digital encoders, long-range measurements, automated gaging routines and computing capabilities can bring surface plate measurements to levels of 0.00005" or better.

GETTING MY STARS ALIGNED

Good gage design requires certain basic physical characteristics to guarantee reliable performance. A rigid and sound physical design, for instance, helps ensure that operators have as little influence on the measurement as possible. One of the most important of these design principles is that of alignment.

The principle of alignment states that measurement is most accurate when the line or axis of the measurement coincides with the line of the scale or other dimensional reference. Now, in the real world of gages, it is rarely possible to design a gage in which the scale and axis of measurement actually coincide. But the scale and axis should be as close as possible, and definitely in the same plane.

Probably the simplest way to visualize this is in a caliper—whether it be a vernier, digital or dial caliper. They all rely on certain alignments of the jaws to assure correct measurement. While the caliper may not be one of the most highly accurate tools in the metrology tool box, it does typify the types of errors that can be found in much more accurate gages, such as a horizontal measuring machine which needs to be able to perform to micro-inches.

First, look at the caliper in Figure 1a. It is in perfect condition, with a straight beam, highly machined and straight surfaces, flat jaws which are square to the beam, and a perfect scale. You can see that the line of measurement is pretty well displaced from the line of the scale, but it is in the same plane, and in this case, for any given separation of the jaws, the scale reading will correspond to the separation of the jaws. Now, imagine that the reference scale was mounted to the beam of the caliper incorrectly, so that it was not square to the jaws. This is unrealistic, of course, but it does show how taking the scale out of planar alignment can distort the accuracy of measurement.

A more realistic scenario is shown in Figure 1b, where we have added an amplified curvature to the beam of the caliper. With this type of curvature, the distance between the tips of the jaws is very much less than the distance indicated by the scale reading. However, as we move the contact points of the measurement up on the jaws closer and closer to the scale, the reading gets more reliable, since it is closer to the reference.

If we put on our geometry caps, we can think about the actual errors being generated in this example, as shown in Figure 2. Let's say the curvature of the beam is 0.001" over a 10" beam length. There is a useful rule of thumb we can use to help us figure this one out, which is shown in the diagram. It says, when the height of an arc is small in proportion to the length of a chord—which is always the case in examples like this—the apex of the triangle formed by tangents at the ends of the arc is twice the height of the arc.

In our case, since we said the arc height is 0.001", then the height of the formed triangle is 0.002". From this we have some simple right angles to work with, and can calculate the angle between the tangents and the chord to be 2.7°. Now, if we assume the length of the jaws is 2", we can also calculate—I won't make you go through the numbers—that the difference between the distance between the tips of the jaws and the reading indicated on the caliper scale is 0.0016".

Most vernier calipers do not have the resolution to see this small an error, but dial and digital units may have the capability of reading it. But what's important here is that with this type of non-alignment condition we are generating real errors. Now think about this condition in terms of a laboratory universal measuring machine or on a precision jig bore. Here distances could be a lot greater and so could the errors.

Thus, in both hand tools and measuring machines, every effort should be made in the design to make sure all measuring surfaces are aligned to assure best performance.

But what difference does this make to you, the user? How do you tell if your gage is well aligned? With most simple gages, you probably can't, other than to look at the gage with the principle of alignment in mind and decide for yourself how it stacks up. With measuring machines, however, a close look at the specifications for straightness of the ways and squareness will give a good indication of how closely the designers aligned their components.

LET'S PLAY TWENTY QUESTIONS To Help You Select the Right Gage and Master for Measuring Your Part

You will soon be going into production with a new component. There are six or eight ways you could measure the part and dozens of products that might do the job. Instead of getting all stressed out about making the decision, let's look at your problem from a different perspective. Let's make a game of it.

Twenty Questions is a game in which you try to discover the person, place or thing your opponent is thinking about by asking him a series of questions that can be answered by 'yes' or 'no.' A good player uses the process of elimination to zoom in on the correct answer quickly. You can go about solving your gage selection dilemma in this same way, with a few important exceptions: The answers won't be 'yes' or 'no'; instead of keeping the answers in your head, you should record them; and instead of making up your own questions, I'm going to give them to you.

1. What is the nature of the features to be inspected? Are they flat, round, or otherwise? ID or OD? Easily accessible, or next to a shoulder, inside a bore, or a narrow groove?

2. What level of accuracy are you looking for? A 10:1 ratio of gage resolution to tolerance is the popular rule of thumb.

3. How much are you willing to pay for super accuracy? Before setting up a gaging operation for extremely close tolerance,

verify that a high level of accuracy is really necessary.

4. Will your gaging process be subject to a GR&R study, and if so, how will it be structured? If passing GR&R is one of your requirements, you should be prepared to discuss the details with your gage supplier.

5. How important is gaging throughput? If a fixed gage will save a thousand hours of labor over the course of a production run, it may pay for itself.

6. How long is this job going to last? If the particular job has a short life, high-throughput measurement may be too costly.

7. How about flexibility? Sometimes it's appropriate to buy a gage based on overall shop requirements instead of one that measures a specific dimension with optimal efficiency.

8. What do you intend to do with the reading once you get it? Will you need digital output?

9. How important is ease of use? Especially for shop-floor gaging, you want to reduce the need for operator skill and the possibility of operator influence.

10. Is your ideal gage one that can be maintained or is it a throw-away? Gages that can be reset to a master to compensate for wear are generally more economical, but may require frequent mastering to ensure accuracy.

11. Is the part dirty or clean at the stage of processing in which you want to measure it? That may affect labor requirements, maintenance, and the level of achievable accuracy, or it might steer you toward air gaging, which tends to be self-cleaning.

12. Will the gaging environment be subject to vibration, dust, changes in temperature, etc?

13. Would it be better to bring the gage to the part, or vice versa?

14. What happens to the part after it's measured? Are bad parts discarded or reworked? Is there a sorting requirement? This question may alert you to the potential of automated parts handling for improving efficiency.

15. Is the part compressible? Is it easily scratched? Many standard gages can be modified to avoid such influences.

16. Does the machine tool impose certain geometric and surface finish irregularities requiring measurement? If so, what is the nature of these deformations?

17. What kind and grade of master do you need? Masters are graded as Z, Y, X, XX, and XXX, with Z being the least accurate and the least expensive and XXX being the most. The class you buy is determined, again, by the ten-to-one rule; but this time in comparison to the gage, not your part.

18. What about master materials? It will depend on your gaging environment. Steel is least expensive and is preferred where there is temperature cycling, because it expands and contracts in proportion to most parts. Chrome plating protects against corrosion. Carbide masters, which are the most expensive, are highly resistant to abrasion and corrosive chemicals. Unlike steel, however, they exhibit only a third of the thermal expansion and contraction.

19. What's your budget? If you absolutely cannot come up with the funds for the gaging solution of your dreams, you'll have to go back over the questions to see where you can compromise.

20. What do you do when you've answered all the questions I gave you and you still don't know which gage is best? The answers you have written down to the first 19 questions are a good starting point for a meaningful

discussion with your gaging supplier. Throw the ball in his court and let him help you.

FIXTURES ARE A COMMON SOURCE OF GAGING ERROR

As a gaging engineer, my concept of a gage includes both the measuring instrument and its fixture. Assuming you are dealing with a reputable supplier, and your instrument was engineered to do its job as intended, there is probably little you can do to improve its accuracy, aside from throwing it out and spending more money. So we will concentrate on the setup, which is a common source of measurement errors.

The fixture establishes the basic relationship between the measuring instrument (for example, a dial indicator) and the workpiece, so any error in the fixture inevitably shows up in the measurements. Many fixtures are designed as variations of a C-frame shape and, as such, have a substantial cantilever that is subject to deflection. This problem is greatly reduced if the fixture is a solid, one-piece unit.

Most fixtures, however, consist of a minimum of three pieces: a base, a post, and an arm. These components must be fastened together with absolutely no play between them. As a rough rule of thumb, any movement between two components will be magnified at least tenfold at the workpiece. Play of only a few millionths can, therefore, easily accumulate through a couple of joints so that measurements to ten-thousandths become unreliable, regardless of the level of discrimination of the instrument.

Because such tight tolerances are required—tighter than you can perceive by eye or by touch—it is often essential that fixtures have two setscrews per joint. No matter how tightly a single setscrew is tightened, it often acts merely as a point around which components pivot.

Lost motion due to play between fixture components is dangerous. Assuming that the gage is mastered regularly, a fixture with loose joints may still provide accurate comparative measurements. There are two places in a gage, however, where loose assembly may produce erratic readings, making the setup completely unreliable. Most dial indicators offer optional backs and sensitive contacts that are designed to be changed by the end-user. Looseness of these two components is among the most common sources of gaging error. These are often the first places a gage repair person looks to solve erratic readings.

Fixtures must be designed to position workpieces consistently, relative to the measuring instrument. This is critical if the master is a different shape from the workpiece. For instance, when using a flat gage block to master an indicator that is used to check ODs on round workpieces, the fixture must position the workpiece to measure its true diameter—not a chord.

The use of masters that are the same shape as the workpiece avoids this problem and another one that can be more difficult to isolate. After repeated measurements, round workpieces may wear a hollow, allowing accurate comparative measurements, while flat gage blocks may bridge the wear, introducing a source of error.

Regardless of its complexity, your gage fixture is the key to accurate measurements. Make sure there is no play at its joints. Check that the instrument itself is assembled securely. And confirm that the gage measures workpieces and masters at identical locations.

WHERE THE RUBBER MEETS THE ROAD – A PROBING LOOK AT PROBES

The capability of a measuring instrument often comes down to how the contact point interacts with the parts being measured, i.e., the probe or contact. Here are some things to keep in mind when using a contact tip or probe arm as part of your measurement.

Many contact points are made out of a single piece of material. Some, however, consist of ruby or diamond inserts swedged or glued into the tip. Rubies are often used on surface finish probes, while the diamond contacts may be used on millionth class gages or where wear may be deemed extreme. Not infrequently, these ruby or diamond inserts become loose or even fall out. On a surface finish gage, a missing diamond usually will result in the same value being seen no matter what is measured, while a loose contact will typically cause apparently valid, but non-repeatable readings from the gage. A loose contact should be one of the first things checked when this condition is seen.

The material of the contact can itself affect the reading in a number of ways. Certain materials don't mix well together. When measuring aluminum, for example, you should stay away from carbide contacts. Carbide is porous, and aluminum can imbed itself into the contact. Over time this builds up and can produce an offset in the readings. Even though the gage is mastered, the measuring loop has been changed and incorrect readings will result.

Contacts should be inspected for flats and scratches caused by continuous wear. Just as material can build up on contact, it can also be removed. Flats on a spherical contact will produce offsets. Worn areas in a caliper will produce inconsistent readings. Scratches can raise high points on the measuring surface and cause errors. When gages go out for calibration, a complete inspection of the contact is required.

Gages are designed to be used with the correct probe for the application. Sometimes, in an effort to get a gage up and running again, contacts are substituted. This is usually not a good idea, but if you must, use flat contacts when measuring round parts and radius contacts when measuring flat parts. Using the wrong combination will make the measurement very difficult, or if the contacts are not parallel, incorrect.

Probe radius is also important. Some gages require a specific radius for their application in order to meet an industry-wide specification. For millionth measurement, for example, contact penetration is dependent on the geometry of the radius. Changing this will affect the performance of the gage and prevent correction factors from being applied correctly. Always verify that the geometry of your probe meets specifications.

The same is true with surface finish probes. There are specific contact point radii called out as part of the surface finish parameter. Using a 0.0004" instead of a 0.0002" radius probe will provide completely different results.

Lever probes on geometry gages or contour systems can be very long – sometimes up to 10". For contacts this long special designs must be used to make sure they are as stiff as possible. Otherwise, there is a chance of flexure or vibration in the probe becoming part of the measurement. This will demonstrate itself as noisy, unrepeatable readings.

Gage readings generated by lever probes may also need to be adjusted to compensate for their length. Ratios are used to make these calculations, based on probe length, say 2 to 1. However, while the contact may be designed properly, the actual contact itself may not be quite to print and the ratio may have to be adjusted accordingly. To avoid this problem, the measuring system should be calibrated with the probe as part of the measuring loop, and any discrepancies calibrated out of the result.

Contact points react differently under pressure. Specifications for compressible materials show very well-defined characteristics for size, shape and finish. For example, using a .5" flat contact in place of a .125" contact greatly reduces the ounces or pounds per square inch of force on the material and will result in two completely different readings.

Getting closer to your probes and knowing how they are used will definitely improve your gaging performance.

DIMENSIONAL COLLATERAL: Do Two Sines Equal a Cosign?

It is not just a simple irony to say that comparative gages have their greatest accuracy at zero. And it is for this reason – even though such a gage could provide a direct reading measurement – it is always best to use it as a comparator. However, one of the most common sources of error when using a comparative gage over long range is cosign error. If you are concerned with reliable measurement, you need to understand the different ways cosign error can influence a measurement.

Cosign error is most typically seen with test style indicators and lever type electronic probes doing run-out and cocentricity checks on shafts and bores, or in engineering and tool making, doing checks of parallelism and alignment of flat faces. With a test style indicator, accuracy is greatest when the axis of the contact point is perpendicular to the measuring direction (Fig. 1). This is seldom the case, however, and as the angle of the contact to the surface increases, the amount of vertical distance encompassed (change in height) also increases. The result is cosign error. Tables can be used to correct for this error as follows, where A is the angle between the probe and the surface of the part

Angle A	Correction Factor
5º	.996
10º	.985
15º	.965
20º	.940
30º	.866

In circumstances where a larger cosign error exists – i.e., where the angle of the probe is greater than 30º - it may be better to zero the comparator closer to the actual part size. This will minimize the cosign error in the reading. To do this, select a zero master that is closer to the calculated reading than the actual standard size.

In general, the rule is to always try to maintain the probe angle to within +/- 15º in either direction. There are also special contacts available that help minimize this type of error with a special involute shape manufactured into the contact.

Another place where cosign error can have a negative effect is in a standard benchtop comparator. If the axis of the indicator is out of alignment with the line of measurement on the part, then a cosign error will result. A one-degree out of alignment condition starts to become noticeable (Fig. 2). If the indicator is set with a 2" master and a part is placed in the gage, a 0.050" deviation will result in a 0.00001" error, as follows:

Change in height = X
X = (deviation) x (cos 1")
= (0.050") x (.99985)
= 0.04999"
(deviation) – (change in height) = error
0.050" – 0.04999 = 0.00001"

While this may not be that serious an error for most measurement applications, it does become important when performing gage calibration.

Although these types of cosign errors seem to get the most recognition, they are the least serious of the errors caused by gage misalignment. In the same example, if a flat contact was used on the gage (rather than the normal radius version, as is most common) the error becomes a function of the radius of the contact surface (Fig. 3). Stated mathematically, this is as follows:

If the misalignment is 1º, the angle of the contact face to the surface is 1º, and the diameter of the contact is 0.250" (radius is 0.125"), then:

Error = (radius) x (sin 1º)
= (0.125") x (0.01745)
=0.0022"

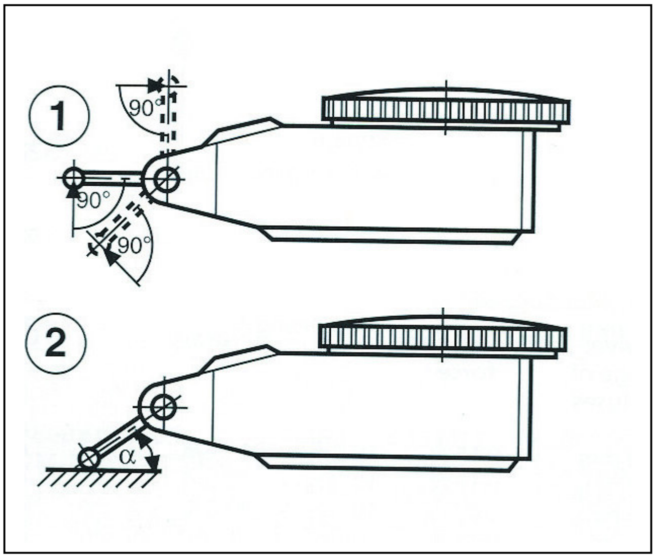


Fig. 1 ***Measurements should always be made at 90º to contact***

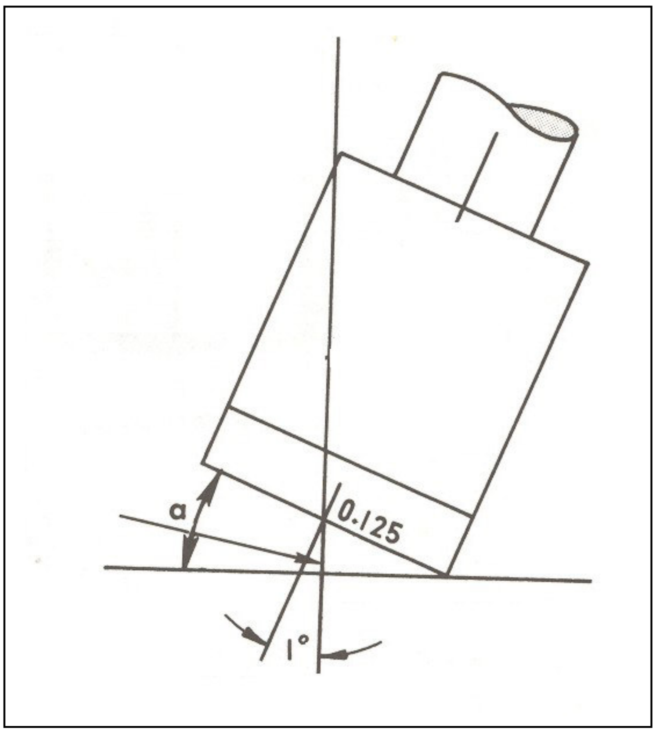


Fig. 2

This error is more serious than the previous example of cosign error. Such a misalignment in a micrometer or snap gage would repeat this error at each contact surface. The example also shows why flat contact points should only be used when absolutely necessary. Using a spherical point eliminates part of this error, but not all of it. Since both the contact point and the part being measured are compressible, there is area contact. With area contact comes positional error where sine error can be introduced. But we'll talk about that later.

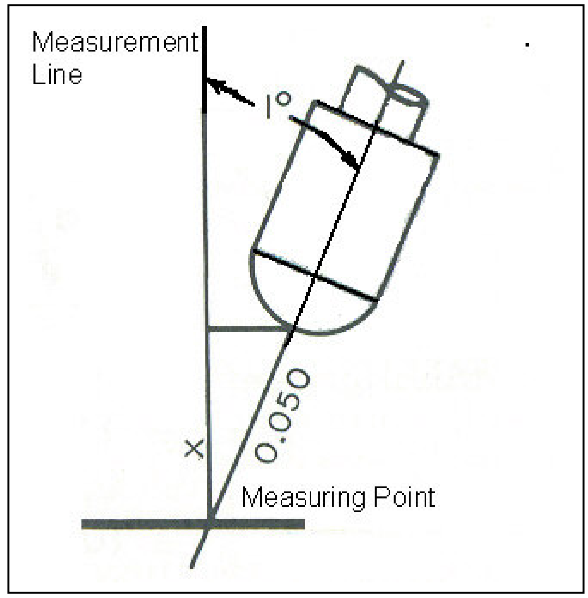


Fig. 3

GETTING MY STARS ALIGNED

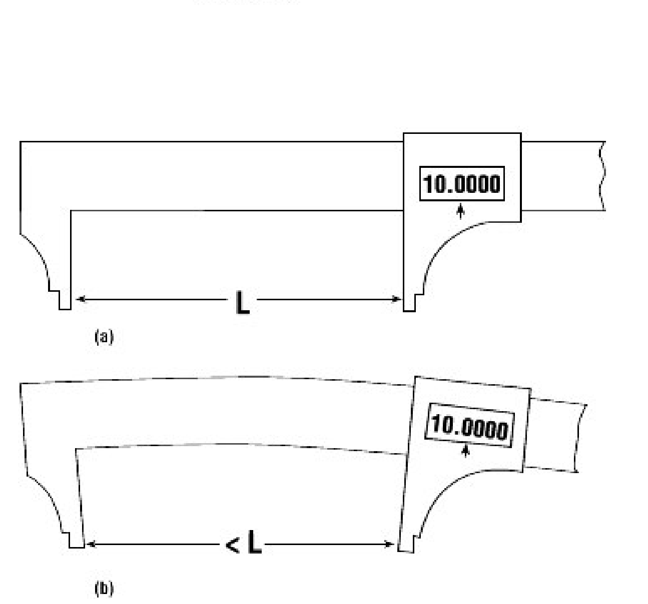
Good gage design requires certain basic physical characteristics to guarantee reliable performance. A rigid and sound physical design, for instance, helps ensure that operators have as little influence on the measurement as possible. One of the most important of these design principles is that of alignment.

The principle of alignment states that measurement is most accurate when the line or axis of the measurement coincides with the line of the scale or other dimensional reference. Now, in the real world of gages, it is rarely possible to design a gage in which the scale and axis of measurement actually coincide. But the scale and axis should be as close as possible, and definitely in the same plane.

Probably the simplest way to visualize this is in a caliper – whether it be a vernier, digital or dial caliper. They all rely on certain alignments of the jaws to assure correct measurement. While the caliper may not be one of the most highly accurate tools in the metrology tool box, it does typify the types of errors that can be found in much more accurate gages, such as a horizontal measuring machine which needs to be able to perform to micro-inches.

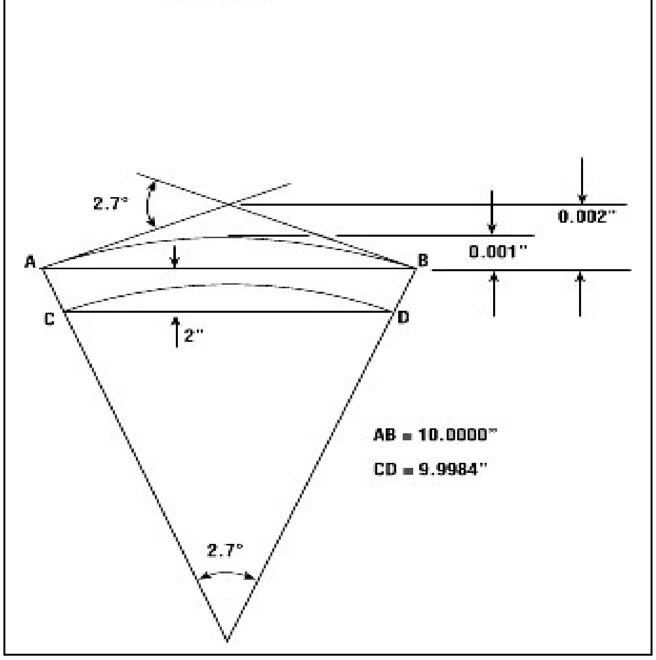
First, look at the caliper in Figure 1a. It is in perfect condition, with a straight beam, highly machined and straight surfaces, flat jaws which are square to the beam, and a perfect scale. You can see that the line of measurement is pretty well displaced from the line of the scale, but it is in the same plane, and in this case, for any given separation from the jaws, the scale reading will correspond to the separation of the jaws. Now, imagine that the reference scale was mounted to the beam of the caliper incorrectly, so that it was not square to the jaws. This is unrealistic, of course, but it does show how taking the scale out of planner alignment can distort the accuracy of measurement.

FIGURE 1



A more realistic scenario is shown in figure 1b, where we have added an amplified curvature to the beam of the caliper. With this type of curvature, the distance between the tips of the jaws is very much less than the distance indicated by the scale reading. However, as we move the contact points of the measurement up on the jaws closer and closer to the scale, the reading gets more reliable, since it is closer to the reference.

FIGURE 2



If we put on our geometry caps, we can think about the actual errors being generated in this example, as shown in Figure 2.

Let's say the curvature of the beam is 0.001" over a 10" beam length. There is a useful rule of thumb we can use to help us figure out this one, which is shown in the diagram. It says, when the height of an arc is small in proportion to the length of a chord – which is always the case in example like this – the apex of the triangle formed by tangents at the ends of the arc is twice the height of the arc.

In our case, since we said the arc height is 0.001", then the height of the formed triangle is 0.002". From this we have some simple right angles to work with, and can calculate the angle between the tangents and the chord to be 2.7º. Now, if we assume the length of the jaws is 2", we can also calculate - I won't make you go through the numbers – that the difference between the tips of the jaws and the reading indicated on the caliper scale is 0.0016".

Most vernier calipers do not have the resolution to see this small an error, but dial and digital units may have the capability of reading it. But what's important here is that with this type of non-alignment condition we are generating real errors. Now, think about this condition in terms of a laboratory universal measuring machine or on a precision jig bore. Here distances could be a lot greater and so could the errors.

Thus, in both hand tools and measuring machines, every effort should be made in the design to make sure all measuring surfaces are aligned to assure best performance.

But what difference does this make to you, the user? How do you tell if your gage is well aligned? With most simple gages, you probably can't, other than to look at the gage with the principle of alignment in mind and decide for yourself how it stacks up. With measuring machines, however, a close look at the specifications for straightness if the ways and squareness will give a good indication of how closely the designers aligned their components.

MAGNIFIED OBJECTS APPEAR CLOSER THAN THEY ARE

Looking through some older electronic and air gaging catalogs, I noticed a term that often appeared was "magnification." In today's world of digital indicators and amplifiers this term is often left out of the description, simply because digital electronics work a little differently than older, analog amplifiers. Today, the term magnification is more apt to be used with optical comparators or vision systems because these do what the word implies. The trouble is, many people take the wrong implication.

Optical comparators use a form of magnifying glass, the origin of which goes back nearly 2000 years. Magnifying something is really the process of making something bigger, but only in appearance, not in physical size.

The magnifying glass was first used in the quality world to enhance the ability of human eyes to see certain aspects of an object. Through the use of these lenses, early users were able to discern features that could not be seen otherwise. But while early optical instruments were able to make objects appear bigger, they did not have the capability to actually perform measurements. To be able to measure, you must first have some standard to compare the measurement to.

The first use of magnification to measure with optics was the shadowgraph. In these instruments, projecting light over an object created a shadow. The magnified image was superimposed on a ruler that acted as the reference standard. The lenses were made and positioned to magnify the image to a certain multiple of the original size, e.g., 5X. Optical gaging advanced another step when micrometers or indicating scales were added to the position devices on the gage. With these, actual measurements of the parts could be made, using the micrometer scale as the measurement standard.

In all of these examples, the use of magnification is simply to make the object being observed actually appear larger.

But magnification is also used in dial indicators and in any electronic amplifier that has an analog meter as part of the readout. In these cases, the readout hand (the dial indicator hand or amplifier needle) is moving more than the actual displacement of the sensing member. In a dial indicator there are gears that act like levers to magnify the movement seen at the indicator contact point. With an electronic amplifier there is circuitry that amplifies the input signal from the sensor. Amplification is much like magnification, except that the amplified electrical signal is actually made larger, as opposed to simply appearing to be larger. But the end result of the amplification of the electrical signal is a way of making a meter hand move to represent the magnified displacement.

Air gages also have used the term magnify to express their measuring capabilities. Often they will refer to having a 2500 or 5000 or even a 10,000 magnification. But what this magnification is referring to is actually how much more the meter hand is moving than the actual sensing end is moving. In truth, we're talking about signal amplification, but the end result is to make the object appear bigger.

But what does the term "2500 times magnification" actually mean? While not all amplifier systems are quite the same, they still utilize the power of magnification.

In the simplest example, if the actual scale of the electronic amplifier, or air gage, is 7.5" long, and the total range of the measuring instrument is 0.003", then the magnification is 2500 (7.5/0.003 = 2500). Now if we had the same length of indicating scale, but the measurement range of the sensor was 0.015", the magnification of the system would be 5000. You can also use this formula to figure out the length of the scale on your amplifier. For example, if the manufacturer of your display states that the magnification is 16,000 and the measuring range is 0.0005, then the length of the scale is 16,000 x 0.0005 and your scale is 8" long.

Why is any of this important? Because users are too often fooled into thinking that higher magnification means better or more accurate measurement. It does not. Why? Because any error inherent in your measurement is also going to get magnified just as much. That is what gaging uncertainty is all about. But that's a topic for another column.

The point to remember is that whether you are actually viewing something that appears bigger, as on an optical comparator, or watching the needle of an amplifier move, you are seeing a magnified result, not necessarily a more accurate one.

PLATE GAGES
4 to 5 You'll Get it Right

Plate gages are a mainstay in the bearing industry, or anywhere that fast, accurate readings of ODs or IDs are needed. You've seen them around: the bench mounted ID/OD comparative gage with the tilting stage plate to set and locate the part being gaged. This basic design, which has been around for over 50 years, is convenient for fast, comparative gaging of flat and relatively thin-walled parts, such as ball and roller bearing rings, where diameter measurements must be made in a plane parallel to at least one of the faces, and sometimes at a particular depth on the ID or OD. Sometimes the location might be the minimum or maximum diameter of the ball bearing race.

The gage consists of a plate that is ground flat, and may incorporate some wear strips on which the part to be gaged is rested. In many cases, however, the plate is no more than a protected surface for the gaging mechanism. Instead of resting the part on the plate, which could cause it to wear and destroy the reference plane, the gaging surface is built into the sensitive and reference contacts of the gage. It is much easier and less costly to replace the contacts on this design, rather than to replace or regrind a reference plate. This design also provides less surface area for dirt or chips to get into the measuring loop and potentially affect measurement results.

There are two types of contact arrangements in these plate gages: a “T” plate design and a “V” plate version. With either version there are movable reference and sensitive contacts that are set close to the diameter to be measured.

The “T” plate design is the most common and probably the most familiar. Since the reference contact and the sensitive contact are in line, the gaging principle is the same as in a portable snap gage. There is a difference in plate deign, however. The contacts used on the plate gage are not flat and parallel as in a snap gage. They are generally curved or “donut”-shaped, which calls for some special consideration. This means that the gage may not necessarily pick up the max or min diameter of the part every time. Some slight “swinging” of the part through the contacts is necessary to identify the min or max position. The second reference contact on the “T” can help locate the part. However, it should be used to position the part close to the true diameter. It should be set to produce a reading slightly outside of the min or max value. Otherwise, if it is set to be exactly on the “zero” diameter, any other position would produce a chord reading and not read the true diameter of the part.

The other contact configuration is the “V” plate design. This design incorporates two reference stops, one at the top of each arm of the “V”, that must be adjusted symmetrically to assure that the part is staged on the center plane of the “V”. This double stop has a locating effect similar to that of a vee block and provides positive and precise location of the part on the gage. This greatly speeds up the measuring process, taking some of the operator involvement out of the measurement, and is especially useful when the part might contain an odd lobing characteristic from the machining process. However, there is a drawback to this type of contact arrangement. Since the sensitive and reference contacts are not in a direct line, there is not a one-to-one relationship between sensitive contact movement and the diameter. Thus, there are two special considerations that should be borne in mind when using this type of gage. The first is that the angle between the reference contacts determines the multiplier needed to determine the measurement, just like the multiplier used when measuring a diameter on a vee block. In most cases this angle is 60º and the ratio is 4:5. This means that for every four units seen by the indicator, 5 units come out (which is another way of saying the sensitive contact is multiplied by 1.25 to get the correct result).

The other thing to remember about this arrangement is that these configurations work only for comparative readings and can not be stretched into the “absolute measurement” world. This is because there is a window of accuracy wrapped around the angle setup for the reference contacts. But if the sensitive contact is moved significantly away from or toward the reference contacts – as would probably happen in an absolute measurement scenario – the angle relationship changes. This changes the multiplier needed to get correct results. To correct for this, a scaling multiplier based on the measurement size and the location of the contact would be needed. It could be done, but it’s pretty complicated for a bench fixture gage.

Fortunately the user need not worry about these angles, ratios, and long-range measurements. The gages take all this into account, and have been doing so for a long time with proven success.