GET READY FOR THE MICROINCH REVOLUTION

Many of us remember when the typical tolerance for machined parts shifted from thousandths to "tenths," and we had to adjust both our production techniques and our QC measurement methods. As ever more technical products make the need for precision even more profound, a similar shift is now under way, toward millionth-measurements. This time, our gaging methods will have to change radically.

Previously, we focused much of our attention on the gage itself: as long as the instrument was designed to the required degree of accuracy and maintained properly, we could usually get by, even at the "tenths" level. Now that we're trying to measure tolerances of 50, 30, or even 20 millionths, we must shift our focus to the measurement process and the environment in which it takes place. Where temperature and cleanliness were formerly somewhat abstract issues, they now become essential concerns.

According to the old gage-maker's 10:1 rule of thumb, when measuring tolerances of 30 millionths, the gage should demonstrate repeat accuracy of 3 millionths. But consider this: a difference of 1°F between the part, the master, and/or the gage can introduce an error of 3 millionths. In other words, if we don't control thermal influences, we give up all hope of repeatability.

Microinch gaging therefore must be performed in a controlled environment -- a special room that is thermally insulated from the shop floor. Temperature should be kept as close to 68_ as possible, and changes must not exceed 2_ per hour. When a part comes in from the shop, it should sit for several hours on a heat sink (a large steel plate), to bring it into equilibrium with the master and the gage before being measured. Even with all of these precautions, the gage should be mastered frequently.

The gage should be protected from the operator's body heat, and his breath, by a clear plastic shield or full enclosure. The operator should not touch the parts or masters directly: insulated tweezers, gloves, or similar measures should be employed.

Elaborate measures are also required to combat the problem of contamination. Relative humidity in the room should be kept below 50% to inhibit the formation of rust. Parts must be thoroughly cleaned of dirt and even thin oil films prior to gaging. The choice of cleaning solvent will vary with the application and may require some trial and error to ensure that the solvent itself doesn't leave a film. It will be necessary to regularly clean the entire gaging area, plus the gage and masters, to remove dust, skin oils, etc. Even the choice of furniture upholstery and the clothing worn by operators must be considered: natural fibers shed more dust than synthetics. The room should have an air lock, and unqualified personnel should be prohibited from entering. If there is a computer printer in the room, it should be in an enclosure, and single-sheet paper feeding should be used: paper dust may released into the air when tearing continuous forms along their perforations.

At microinch tolerances, dimensions change so readily that it may be more practical to check part relationships (i.e., clearance) than absolute dimensions. "Match gaging," which is sometimes associated with imprecise process control, can be the best and easiest way to ensure that parts will fit together with the required clearance.

Surface finish and part geometry become critical parameters at the microinch level, and for any degree of repeatability to be possible, it is necessary to use witness marks, or some other method to ensure that a part is always measured at the same location. The whole subject of mastering, calibrating, and certifying a gage to millionths is important enough to deal with at length in a future column.

Even with sophisticated gages that are fully capable of the task, measuring to millionths remains a challenge. It requires thorough planning, careful selection of conscientious personnel, and significant investments in training and facilities, as well as a good understanding of all the variables that can affect microinch dimensions. It may be tempting to just buy the new gage and give it a go, but I can guarantee you'll spend more time figuring out your problems and ways to fix them than you would by doing it right in the first place.

THE MECHANICS OF MILLIONTH MEASUREMENTS

In a recent column we looked at some of the challenges inherent in measuring parts to microinch tolerances. We discussed the need for a climate-controlled environment and absolute cleanliness, but we've only scratched the surface (so to speak). Special attention must also be paid to the selection of the gage and readout, and to mastering.

If you're checking parts for tolerances of 10 microinches, or checking gage blocks, rings and discs to millionths, you'll need resolution (i.e., minimum grad value) of 1 microinch, or maybe even 0.1 microinch, on the gage readout. But beware of excessive magnification. Some gage manufacturers create the appearance of microinch accuracy by supplying an electronic amplifier, with units reading in millionths, on a garden-variety gage. Because the average shop-floor gage is mechanically repeatable to only 50 millionths or so, what you really get is a highly magnified look at the gage's repeatability error. The resolution of the readout should accurately reflect the precision (i.e., repeatability) of the gage itself. This can be checked by repeatedly measuring a part under controlled conditions. If the reading varies by .000005" or more between trials, the gage may be incapable of handling microinch inspection duties.

When measuring high-accuracy IDs, gages typically contact the workpiece with up to 4 ounces of gaging force. At microinch tolerances, this can produce measurable deflection of the jaws. That deflection may be unavoidable, so repeatability demands that it remain constant from one trial to the next. A frictionless mechanism, such as a reed spring arrangement, is therefore essential to maintain the gaging force constant to within 1/2 gm.

Normally, we rely on a master to assure the accuracy of a gage. But if we're using the gage to measure a master, we have to go one step further and refer to certified gage blocks to master the gage. This is relatively straightforward for outside measurements, but more complex for inside measurements.

There are two accepted methods: In the first, a single gage block or a stack of blocks is used to set a pair of caliper blocks at a precise distance. The blocks are held together with clamping rods, with the caliper blocks extending over the gage blocks on both sides. (See Figure 1.) The gage is mastered to the distance between the caliper blocks, checking at both ends for parallelism error. Ball feet may be snapped onto the block assembly: this makes it easier to move around on the table using insulated forceps or other tools, and helps to minimize the transfer of heat from the operator's hands.

In the second method, two or more blocks are wrung to a true square, with enough overhang on the topmost block to fit over the gage contacts. A second set of blocks is wrung against an adjacent edge of the square to check for squaring error. (See Figure 2.) This setup is less subject to parallelism error than the first method. In both methods, the operator should wait at least three hours after assembling the blocks, to give temperatures a chance to normalize.

When measuring master rings, it is necessary to account for geometry errors, as well as surface finish, scratches, waviness, and other microinch imperfections. Measure Class XX masters (tolerance = .00002" for sizes between .029" and .825") at a depth of 1/16" in from both ends, and in the middle of the ring. This avoids the bellmouth conditions likely to exist near the ends, and detects most barrel-shape, hourglass, and tapered conditions.

For Class XXX masters (tolerance = .00001" for sizes between .029" and .825"), the drill is even more rigorous. Confine all measurements to a 1/4" tall band in the center of the ring, and take a total of six measurements: at the top, middle, and bottom of the band, in both north/south, and east/west orientations.

The point here is not to find and discard masters that show variation of a millionth or more. When working at the microinch level, a certain degree of uncertainty is inevitable. The objective is to minimize the uncertainty that the master contributes to the overall measurement process.

DON'T WRING YOUR HANDS, WRING YOUR GAGE BLOCKS

You need a master for something you have to measure, so you reach for a set of gage blocks and begin creating the dimension. But how are you going about it? Some machinists, with experience using gage blocks, will begin creating the desired dimension by starting with the largest block first and grabbing blocks as they go. Then they get stuck and start wringing their hands.

However, there's more to combining gage blocks than just "stacking" blocks. When done properly, you can create any dimension from zero to four inches, to the nearest tenth of a thousandth, never using more than four blocks or never using more than one from each series of blocks. In addition, you are assured of minimizing wringing error and randomly spreading the usage among all the blocks, thus reducing wear on the blocks.

Let's say the dimension we need is 1.3248 inches. We've got four series of blocks, as shown in Table 1. Now, to create 1.3248inches, rather than saying, "I need a one inch block," we start at the right side of the dimension and work backwards, with the goal of creating zeros all the way across.

To get rid of the 8, there's only one series with an 8 in the fourth place: the Tenths. So we select the 0. 1008-inch block. Subtract from 1.3248 inches, we're left with 1.2240 inches.

Now we want to get rid of a 4 in the third place. We have more than one in the Thousandths Series blocks with a 4 in the third place-0. 104 inch, 0. 1 14 inch, 0. 124 inch, 0. 134 inch and 0. 144 inch. To get rid of the 4, as well as the 2 in the second place, we select the 0. 124-inch block. Subtracted from 1.2240 inches and we are left with 1. I 000 inches. See how quickly this system gives us round numbers.

We have a 0.1000 block in the Fifty Thousandths Series, which leaves us with 1.0000 when subtracted from our number. Finally, to get rid of the one-inch number, we have the one-inch block in the Inch Series. So, the math for 1.3248 inches looks like that shown in the example above.

By working from right to left, we have created zeros all the way across. We have not used more than four blocks, and only used one block from each series.

We could create the same dimension using many more blocks, but there are only three "wrings" in a stack of four blocks. There could easily be wringing error of four-millionths per wring. The more blocks we use, the greater the wringing error, and the more the blocks are exposed to the shop environment, where they may get dirty, scratched or lost. We need to combine gage blocks properly for the same reasons we need to give them lots of care.

CLEAN IT UP AND WRING IT DRY

There's probably nothing in your shop that is made to the same high level of precision as your gage blocks, with their manufactured tolerances closer than a few millionths. The

Hubble Space Telescope gets mirror envy when it thinks about the smoothness and accuracy of a common gage block. It requires just a few, but nonetheless important, care and maintenance measures to retain that extraordinary precision for years.

Cleanliness is critical; it is Rule Number One. Never wring, or use in any other way, gage blocks that have been exposed to chips, dust or dirt. Blocks that have been exposed to cutting fluids must be cleaned, without fail, prior to wringing, or the metal particles held in suspension will surely wear the blocks' surfaces.

To clean blocks, use filtered kerosene, a commercial gage block cleaner or some other high-grade solvent that doesn't leave a residue. Wipe them dry with a lint-free tissue. Even if you are taking "clean" blocks from their storage box, clean them again. They've probably picked up lint or dust while in the case.

Wring blocks together "dry." Rubbing them on your palms or wrists will deposit oils that may assist in bonding the blocks during a wring, but it may also transfer dirt and moisture that can damage the surfaces. If you can't get a good wring dry, use a commercial wringing solution, available at most trade stores.

Don't allow gage blocks to remain wrung together for long periods, because they can become permanently fused to each other. If you use the same setup day after day, make sure you separate and then wring them daily.

Frequently inspect the blocks for nicks, scratches or burrs, and repair or replace any damaged blocks before using them. One advantage of combining blocks by the method described in last month's column (by zeroing" the dimensions in order, from the smallest decimal place to the largest) is that wear is randomly spread among the entire series of blocks. But if even one of those blocks is damaged, then you will end up randomly transferring scratches among your entire collection.

When you are through, make sure you always clean the blocks before putting them away in their case, and coat them with a non-corrosive oil, grease, or a commercial preservative. If you don't coat them, they will rust, even in the box. Just think what corrosion will do to the surface of blocks when you are wringing them.

Regard the case as part of the working system of gage blocks. Return blocks to the proper slot in their case as soon as possible. Beyond protecting them from dust, the case ensures that the blocks don't get tossed haphazardly in a random box, where they can easily damage one another. The labels on the case are much easier to read than the numbers etched on the blocks themselves, so you will spend less time looking for the right block. And you will be able to see immediately from the empty slots what blocks are in use or missing.

Keep the storage case scrupulously clean, both inside and out. This will serve to remind you and other users that the gage blocks are not just hunks of metal. We are talking precision instruments here, and they must be treated as such to retain that precision.

Finally, don't loan out individual blocks. The minute a set is broken up, all of the above points are likely to go for naught. You can no longer control the conditions under which those blocks may be used, and they may return to haunt you by transferring dirt, corrosion, or scratches to your other blocks. That is, of course, if they return at all.

Keep gage blocks in their storage case, and clean them not only before they're put away, but also when they're taken out. Use filtered kerosene, a commercial gage block cleaner, or other high-grade solvent; wipe the blocks dry with a lint-free tissue; and coat them with a preservative before putting them away.

WORKING WITH YOUR WORKING GAGE BLOCKS

Working gage blocks are the ones used when the rubber meets the road in today's shop environment. Their use is as varied as the number of gage blocks found in a large set. The working blocks have an intermediate grade, and are often used in the inspection or calibration lab, but may also be found out on the shop floor. We are not talking about the Master Gage Block set, which is used as the corporate standard, or the shop floor set which may sometimes level out an old table. As part tolerances become tighter and the resolution of comparative gaging higher, the use of working gage block sets for tool making and part inspection is very widespread.

Of course, the most common use of the gage block is to provide a reference for direct measurement of distances between parallel surfaces, such as widths of grooves, slots, etc. The blocks can be used as a go/no go gage or as a means of setting up a comparative measurement. The ability to stack the gage block set to any length is what makes the gage invaluable as a tool in the inspection lab.

A second important use of the working block is for checking the performance of the shop hand tools and gaging equipment. For example, micrometers and other hand measuring instruments can be checked for linearity (degradation of the micrometer thread). Using gage blocks of different sizes that are stepped, usually in equal increments over the measuring range of the measuring tool, provides a means for checking the performance of the tool. The gage blocks are also useful for setting a reference point on measuring tools where the measuring capacity of the gage is larger than the measuring range of the gage itself. For example a 3" gage block would be used to set the 3" reference point on a 3" - 4" micrometer. With these measuring tools the spindle does not touch the fixed contact, so a gage block provides a precision method of setting a starting point.

Limit gage sets can be created with two sets of gage blocks or gage block stacks set to the high and low limits of the tolerance. These sets would consist of gage block stacks with added contact elements or end jaws all combined together to the limits specified. They provide an easy-to-assemble and reliable means of producing temporary gaging for an unexpected application. However, in actual use it is much more economical over the long run to have a fixed gage made up for these applications, as the constant assembly and disassembly is time consuming and subject to stacking error.

In the manufacturing inspection area a frequent use of these blocks is to set up for comparison or transfer measurements during surface plate work. Using a single block or stack for a height reference is the common approach. By adding another gage block or endjaw, which over-hangs the block, an inside dimension can be established. A base, holding rods, and endjaws, are often found in a gage block accessory kit. They allow the assembly area to perform medium accuracy comparisons with surface plate work. Finally, the use of gage blocks and a sine plate on the surface plate create a very precise angle setup. The double requirement of accurate length and perpendicularity to the base is a perfect use of the working gage block. Using fairly straightforward trig, the right angle reference set up by the blocks and the known length of the sine plate makes for easy angle setup. Just as it's necessary for you to get ready to go to work, gage blocks need to get ready to work also. Since they can't do it by themselves, it's necessary to help them out. Preparation includes making sure they are recently certified, checked for nicks and burrs, and stabilized for the temperature of the work area.

With some care and careful handling, working gage blocks will make a significant contribution to the productivity of a manufacturer.

GAGE BLOCK VERIFICATION

I got a note the other day from a QC manager wanting to know if it would be acceptable for him to verify his gage blocks in-house. "You always say the gage-maker's rule of thumb states that any gage used to verify another gage must resolve to ten times its accuracy," the gentleman wrote. "We've got a perfectly good bench gage here that resolves to millionths of an inch: can we use that?"

The answer, like so many in metrology, is 'it depends.' The rule of thumb does say 10X accuracy, but there are also *fingers*. Take a look at the following measurement requirements for verifying gage blocks, then you decide.

Gage blocks are used throughout the production process, but those used in the inspection area, tool room, or on the production floor are especially subject to wear. Even age can affect the size of a gage block. And with tolerances growing ever tighter, regular verification of gage blocks is now more important than ever.

The most widely used method today is still the comparison of a test gage block to a reference or master gage block of the same size, and then recording and documenting the variation between the two. There are two methods of comparison—comparison by interferometry or mechanical contact methods. The mechanical method is by far the most common in industry today, and it is done on a special class of comparator specifically designed for this purpose.

While these instruments may look and operate very much like typical precision comparators, there are many additional requirements needed to achieve millionth-level measurement gage block verification. This is not to say that other comparators cannot measure to millionths of an inch, but gage block comparators are designed to take these additional requirements into account.

For a 'regular' precision comparator to achieve reliable millionth-level measurements, it must meet some fairly stiff criteria:

- A large and massive base—one that does not change in size quickly with slight temperature changes.
- A rigid base—at this level, bases, posts or arms that might deflect can create errors even bigger than the intended measurement.
- A high-resolution amplifier is needed to discriminate to the tolerances required. Resolutions need to be one millionth of an inch, or even less, and it must be stable and not drift.
- A highly linear gage head that has excellent repeat characteristics.

But for a gage block measuring system, the following characteristics are also needed:

- Two measuring contacts, both contacting the block differentially. This eliminates form error from the block measurement. Because the two surfaces of a gage block are not perfectly flat and parallel, and because any reference surface is also not perfect, size measurements will depend on exactly where the measurement is taken. Contacting at two specific points, exactly opposite one another on the gage block, is the way to get good, repeatable measurements that can be reproduced from year to year.

- Contact points of known material (diamond) and of specific radius.

- Known and constant gaging pressure over the full measuring range.

- The ability to electronically adjust mechanical zero. Mechanical zeroing would be nearly impossible at this high magnification.

- Retractable contacts to eliminate any possibility of scratching the block or wearing the contacts.
- A platen to support—but not measure—the block, with grooves to help keep the block clean.

- A method for positioning the gage block to specified measuring locations as called out in industry standards. New requirements specify blocks be measured at specific locations.

- A means of quickly setting the gage to another size with as little mechanical adjustment as possible. Since a typical gage block set may consist of 81 blocks, the gage should have the ability to set size rapidly, with as little influence on the gage as possible.

Since gage blocks need to be measured with two contacts, differential gaging is a typical method to accomplish this. Differential gaging uses two high precision LVDT type transducers. These are very linear and repeatable over short ranges, and are very good for these applications. But there is also an alternate method available on some systems that is even better.

In any LVDT, there is some very small error stemming from linearity, repeatability, or slight changes in gaging pressure. Eliminating one gage transducer, while still performing a differential check, eliminates any possible error associated with one of the heads. By mechanically creating a differential measurement with a floating caliper, errors can be cut in half and the overall performance of the gaging system improved.

Finally, while gage block comparators are designed for millionth measurement that takes into account all the physics of good gage block verification, software programs further reduce any sources of error. For example, a gage block program can correct for minute errors resulting from gaging pressure of different gage block materials and changes in temperature.

Thus, while there are many systems like bench gages and horizontal measuring machines capable of measuring in the millionths of an inch, only a gage specifically designed to measure gage blocks provides the ultimate system for both speed and performance.

Two excellent references for our QC manager are (a) THE GAGE BLOCK HANDBOOK, NIST Monograph 180, available from the National Technical Information service, Springfield, VA 22161 and (b) American National Standard B89.1.9-2002, Gage Blocks, available from The American Society of Mechanical Engineers.

NEW GAGE BLOCK STANDARD
Location is Everything

One of the few things you can count on in life is that ASME’s Dimensional Standards are relatively stable for a long period of time. This is good because change is a hard thing to deal with – especially in the metrology world. The United States Gage Block Standard has not changed much since 1970 when Federal Specification GGG-G-15B was introduced.

However, there have been many changes over the years in the use of gage blocks: in block materials, in the internationalization of manufacturing, and changes resulting from the influence of new measuring principles such as uncertainty and traceability. Thus, in 1990, ASME B89.1.9 started the ball rolling towards updating the standard by introducing more international influence. Finally, in ASME

B89.1.9 2002, the Gage Block Standard was revised in an effort to bring it closer to ISO 3650, while at the same time incorporating our desire for inch units, square blocks and some of the grade requirements ingrained in North America.

While most of the changes in the new specification don't affect the everyday user of the blocks, they may influence how gage blocks are identified (or graded), how they may be measured, and how the information is presented. The standard has already affected gage block manufacturers in the way they specify their products.

Actually, ASME B89.1.9 isn't bad reading. Besides the normal terms, definitions and tables, it presents some good information on referencing from the old standards to the new, on the handling of gage blocks, and on typical set configurations. It even lists very nicely the differences between previous standards and the new one. This is done to clear up different terminology and to match the different grading conventions, old and new.

As regards grading, there are a couple important items to point out. The first is that grading is now modeled much closer to the ISO method, as follows:

FORMER FEDERAL GRADE	**NEW ASME GRADE**
(GGG-G-15C)	(ASME B89.1.9)
1	00
2	0
3	AS-1
…	AS-2

The other noteworthy change is in the actual tolerance of the blocks. Gone are the unbalanced tolerances such as +16, 8µ" as was seen for a grade 3, 2.0" block. Today, that tolerance is +/- 16µ" for the equivalent grade AS-1.

Finally, a change was made to add a specification for length variation of the block. This was previously referred to as parallelism. Today, each grade has a length variation tolerance that is dependent on the grade of the block. What is also important is that this length variation can be as small as 2µ" and the standard specifies where it must be measured. The new requirement is that all blocks be measured at the gage length (which is the center of the measuring face), and at all four corners. Corner measurements must be taken at approximately 0.060" from each of the side faces, and all of the points measured must not only be within the length tolerance for the grade, but also within a specific variation range for the length tolerance. For example, if the grade length tolerance is +/- 8µ" and the tolerance on length variation is 4µ", then all your measurements must fall within the +/- 8µ" and also not vary very far from each other by 4µ".

While this may not seem to be much of a chore, it really increases the burden for the gage block calibration people who do the actual measurements. Previously, they would make four measurements somewhere on the face of a rectangular block, simply by moving the block around with tweezers (precision tongs). Now that the spec requires measuring at an exact location, measurement is much more difficult and time-consuming for the operator.

To ease this situation, special gage block manipulators need to be incorporated into gage block comparators to position the blocks to the exact locations in each corner, every time and very repeatably. Remember this last statement, because with gage blocks we are in the world of micro-inches. Like real estate, the key to measuring millionths is location, location, location. The better you can position the gage block, the more you increase repeatability and reduce uncertainty.

Eventually all the tools used to calibrate gage blocks will need to incorporate gage block manipulators if calibration facilities are to improve throughput and maintain tight uncertainty levels.

FORMULATING SOURCES OF ERROR IN YOUR FORM MEASURING SYSTEM

It is generally understood that the results of precision measurements – such as from a form measuring instrument – are subject to a number of environmental influences, such as shock, vibration, and temperature deviations. What is less well understood, however, is that the form measuring machine itself can also influence the measurement results. For example, worn probes, excess bearing clearance, natural vibrations, and other factors can all degrade the overall accuracy of a measurement. These measuring system based factors that influence the assessment of form are called 'Measuring Uncertainty.'

Some suppliers of precision parts are required to take the measuring uncertainty into account before delivering their products to their customers. Here's why. Let's say that the specification for radial run-out of a shaft is called out in the tolerance at 3 µm. From documentation we then discover that the uncertainty of the measuring instrument amounts to +/- 1µm. As can be seen in figure 1 then, only shafts with a radial run-out of less than 2 µm can be accepted. Once the measured radial run out values reach or exceed 2 µm, you can no longer exclude the possibility that the inspected work pieces are out of tolerance.

For this reason, it's not too surprising that measurement uncertainties are disclosed for facilities doing measurement standards, such as gage blocks, master rings and discs. But there are also cases where the measuring uncertainties of instruments used for the inspection of products come under scrutiny. Only when you have determined the uncertainty of an inspection system for production parts can you then determine what part of the tolerance band is "left over" for actual production. The drawing tolerances, which are often extremely close, are narrowed even more if the measuring uncertainty is too high. The upshot of this is that imprecise measuring devices increase production effort and, therefore, cost.

The present internationally approved standard for the determination of measuring uncertainty is the GUM method (Guide to the expression of Uncertainty in Measurement). The first procedural step in determining uncertainty is the determination of all the influence quantities. The complexity of a form measurement becomes quite clear during this very first step. Here's a partial list of influencing factors that may cause measurement errors:

1. Examples of environmental influences: Temperature (fluctuations), radiant heat (e.g., from the operator or the lighting), air refraction/gradients (influencing optical based systems, including lasers), humidity, vibrations and shocks.

2. Examples of influences caused by the part being measured: Fixturing method, alignment, distortion through measuring force an dead weight, size and type of the gaging and datum surface(s), roughness of the gaging surface, undetected form errors of the gaging surface, form errors of the datum surface(s).

3. Influences caused by the operator: Misinterpretation of the drawing specifications; excessive clamping force when fixing the part under measurement; selection of wrong probes (Figure 2); selection of wrong parameters (e.g., wrong profile filter, excessive measuring speed); programming errors and computation errors; heat radiation; shocks. For this reason, it is important that operators have comprehensive training in metrology, and in the correct adjustment and operation of their measuring instruments.

4. Examples of influence caused by the form measuring instrument: Deviations of the measuring axes, irregular movement during measurement, errors in the electronic indicating and control system (e.g., rounding errors), software errors.

The choice of measuring instrument has considerable influence on the number of factors that determine the measuring uncertainty. For example, compare a sample roundness measurement on a form measuring instrument with a rotating measuring axis, and a roundness measurement on a 3D coordinate measuring instrument. Using an instrument with a rotating measuring axis, as in figure 3, shows that the influence of stylus ball form errors on the measuring result is negligible. Figure 4, however, shows that this does not apply to 3D coordinate measuring instrument: in this case, the stylus ball deviations have to be thoroughly calibrated before measurement. For this reason, the degree of uncertainty for roundness measurements on a 3D coordinate measuring instrument depends in large part on the uncertainty of probe calibration (into which, in turn, the measuring uncertainty of the calibration standard enters, among other factors).

All these factors, which may significantly influence the uncertainty of form measurements, have to be estimated on the basis of concrete data for the expected value and the standard deviation.

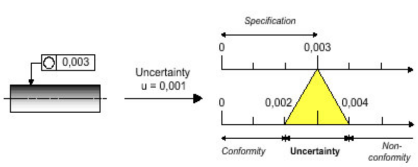

Fig. 1: Influence of the measuring uncertainty on the result of a roundness measurement.

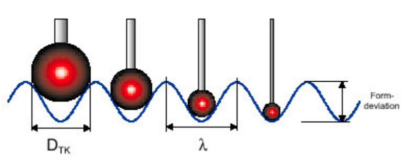

Fig. 2: Influence of the stylus ball diameter on the result of a form measurement.

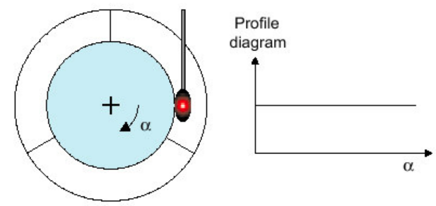

Fig. 3: Influence of the stylus ball's form deviations on the result of a roundness measurement using a Formtester with rotating testpiece.

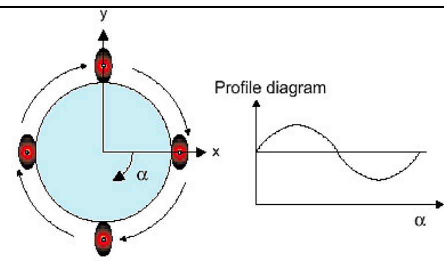

Fig. 4: Influence of the stylus ball's form deviations on the result of a roundness measurement using a 3D coordinate measuring machine.

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For a 'regular' precision comparator to achieve reliable millionth-level measurements, it must meet some fairly stiff criteria:

- A large and massive base – one that does not change in size quickly with slight temperature changes.
- A rigid base – at this level, bases, posts or arms that might deflect can create errors even bigger than the intended measurement.
- A high-resolution amplifier is needed to discriminate to the tolerances required. Resolutions need to be one millionth of an inch, or even less, and it must be stable and not drift.
- A highly linear gage head that has excellent repeat characteristics.

But for a gage block measuring system, the following characteristics are also needed:

- Two measuring contacts, both contacting the block differentially. This eliminates form error from the block measurement. Because the two surfaces of a gage block are not perfectly flat and parallel, and because any reference surface is also not perfect, size measurements will depend on exactly where the measurement is taken. Contacting at two specific points, exactly opposite one another on the gage block, is the way to get goof, repeatable measurements that can be reproduced from year to year.
- Contact points of known material (diamond) and of specific radius.
- Known and constant gaging pressure over the full measuring range.
- The ability to electronically adjust mechanical zero. Mechanical zero would be nearly impossible at this high magnification.
- Retractable contacts to eliminate any possibility of scratching the block or wearing the contacts.
- A platen to support – but not measure – the block, with grooves to help keep the block clean.

- A method for positioning the gage block to specified measuring locations as called out in industry standards. New requirements specify blocks be measured at specific locations.
- A means of quickly setting the gage to another size with as little mechanical adjustment as possible. Since a typical gage block set may consist of 81 blocks, the gage should have the ability to set size rapidly, with as little influence on the gage as possible.

Since gage blocks need to be measured with two contacts, differential gaging is a typical method to accomplish this. Differential gaging uses two high precision LVDT type transducers. These are very linear and repeatable over short ranges, and are very good for these applications. But there is also an alternate method available on some systems that is even better.

In ant LVDT, there is some very small error stemming from linearity, repeatability, or slight changes in gaging pressure. Eliminating one gage transducer, while still performing a differential check, eliminates any possible error associated with one of the heads. By mechanically creating a differential measurement with a floating caliper, errors can be cut in half and the overall performance of the gaging system improved.

Finally, while gage block comparators are designed for millionth measurement that takes into account all the physics of good gage block verification, software programs further reduce any sources of error. For example, a gage block program can correct for minute errors resulting from gaging pressure of different gage block materials and changes in temperature.

Thus, while there are many systems like bench gages and horizontal measuring machines capable of measuring in the millionths of an inch, only a gage specifically designed to measure gage blocks provides the ultimate system for both speed and performance.

Two excellent references for our QC manager are (a) THE GAGE BLOCK HANDBOOK, NIST Monograph 180, available from the National Technical Information Service, Springfield, VA and (b) American National Standard B89.1.9-2002, Gage Blocks, available from The American Society of Mechanical Engineers.