TechTips

Techtips is a collection of useful ideas, techniques, and procedures designed to further EDM knowledge.

Quality & EDM part 3

In this final installment of the series, we will explore the potential sources of variability in the measurement of the parts we EDM.

Only after careful measurement can we honestly say that the parts we make are within tolerance. In many industries we serve, out-of-tolerance parts can literally be a life-or-death issue. Therefore, the certainty of our measurements is critical to successful EDMing.

Many people mistakenly believe that making parts to "tenths" is harder than measuring them. However, nothing could be further from the truth. In fact, to be able to say that a part is "within a tenth", we have to be certain that the accuracy of our measurements is a fraction of the tolerance we are trying to measure.

__Please note__ that the following discussion assumes that your measuring devices are controlled by a calibration system which assures regularly scheduled device calibration and traceability to the National Institute of Standards and Technology.

First, let's examine the four terms that form the foundation of measurement uncertainty:

Figure 1

Resolution

Resolution is the smallest reading that an inspection instrument or process can reliably display. The following are examples of resolution:

- On an "old fashioned" micrometer or caliper, measurement results are determined using graduations and a vernier to interpolate readings between the graduations. The vernier divisions would be the resolution. ***(See Fig# 1)***
- On a dial indicator there are graduations. Usually, it is possible to interpolate readings that are in between graduations. For a .001 graduated indicator dial, the resolution might be .0005. For a .0005 graduated indicator dial, the resolution might be .0002. ***(See Fig# 2)*** For a .0001 graduated indicator dial, the resolution might be .00005.
- On an optical comparator, the resolution is usually a function of the magnification and the thickness of the line on the chart. For 10X magnification, the resolution is typically .0005, since at 10X a .005 line width on the chart can hide an error of .0005 beneath the line. For 20X magnification, the resolution is typically considered to be .0002. For 50X the resolution is typically considered to be .0001.
- For any instrument with a digital readout, the resolution is the least significant digit displayed. For the digital micrometer shown in ***Fig# 3***, the resolution is .00005.

Figure 2

Figure 3

For any measurement, the resolution needs to be a fraction of the total tolerance to be measured. There is general agreement in the industry that the resolution should fall between one fifth and one tenth of the tolerance band to be measured. This means that if you are measuring a tolerance of +/- .0001, the resolution of the measuring instrument should be between twenty and forty <u>millionths</u>!

Repeatability

Repeatability is simply the total variation observed when the same measurement is taken a number of times. Measurement accuracy is necessarily limited by the repeatability of the measuring instrument or process.

Reproducibility

Reproducibility, is variation in the measurement process over a period of time utilizing a variety of samples and a number of different inspectors. During a recent Gage R&R exercise in a Six Sigma class, four Quality Managers measured 6 electrodes known to be within .0002 with a .00005 resolution digital micrometer that had been recently calibrated to .00005 accuracy. A statistical analysis of the measurements performed by these ostensibly skilled quality professionals produced a variability of .001!

Accuracy

Accuracy, in its most simple form, is the difference between the measurement displayed by the instrument or process and the actual value of a traceable calibrated standard.

The potential variation of a measuring instrument or process is a combination of these four factors.

Now let's look at the potential for variability in one, two, and three-dimensional measurements.

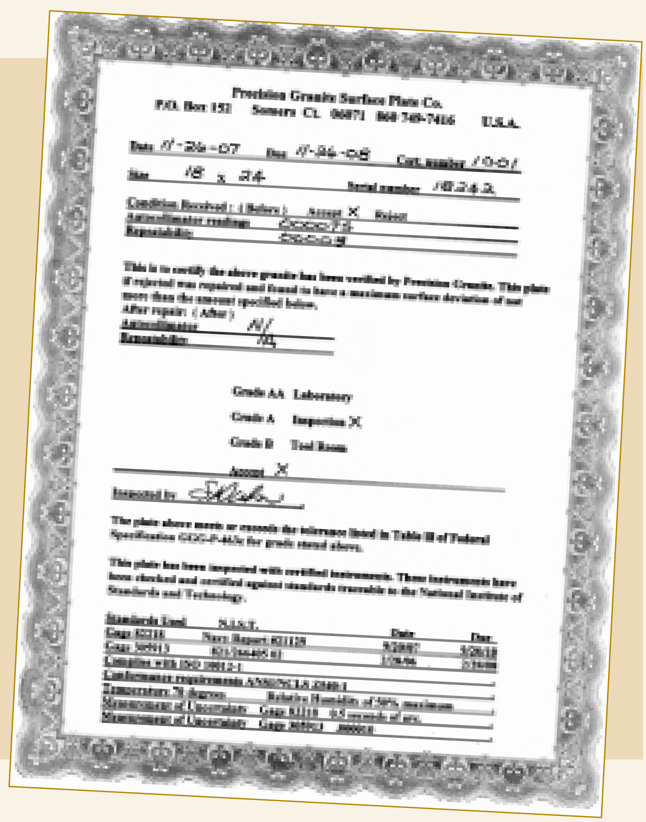
Variability In One-Dimensional Measurement

Two examples which illustrate the variability in one-dimensional measurement are measuring the thickness of a part and checking the diameter of a pin, each of which has a tolerance of +/- .0001.

Measuring Part Thickness

Since, based upon common inspection practice, a .00005 resolution digital micrometer is right at the limit of its capability for such a measurement, let's use a size block and a dial indicator with .0001 graduations for this measurement. The components of variability in this simplest of measurements include:

- Surface plate flatness — Since we will use the indicator to compare the thickness of the part to the size block, we have to assume that the surface of the plate is a flat plane. Most inspection grade plates are flat to within .000075. ***(See Fig# 4)***


Precision Granite Surface Plate Co.

U.S.A.

Grade AA Laboratory

Grade A Inspection X

Grade B Tool Room

Accept X

Figure 4

- Tolerance of the size block — Since most inspection grade blocks are within single digit millionths of an inch, this should not be a factor, even if we are using a stack of blocks.
- Surface roughness of the part to be measured
- Flatness of the part surfaces
- Parallelism of the part surfaces
- Indicator resolution (.00005)
- Indicator repeatability (Also affected by the rigidity of the indicator stand and the flatness of the base of the stand)
- Indicator point angle — Unless the part and the size block are exactly the same height, the difference displayed on the indicator dial can be affected by Cosine error due to the angle of the axis of the point from the horizontal plane. ***(See Fig# 5).***

Even this simplest of measurements is subject to a combined variability that can easily approach the tolerance we are trying to measure.

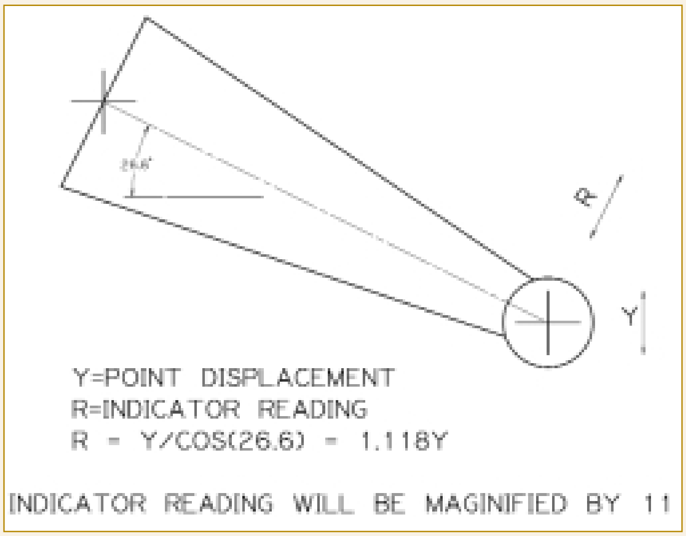


Figure 5

Measuring Pin Diameter:

For this measurement, we'll use a digital micrometer with .00005 resolution. The components of variability of this measurement include:

- Surface roughness of the pin
- Roundness of the pin
- Taper of the pin
- Micrometer resolution
- Micrometer repeatability
- Micrometer accuracy
- Diameter compression — Micrometers are usually calibrated using flat gage blocks. Using the same friction thimble pressure on a pin with only line contact can cause a slight elastic compression of the pin diameter, as a result of high pressure due to the very small contact area.
- Overshoot due to micrometer momentum. Even when using a friction thimble, the speed at which the micrometer barrel is rotated as the measurement is made, can easily affect the reading by at least one or two resolution increments.
- Thermal effects of holding the micrometer in your hand for any length of time

As in the case of measuring the thickness of a part, the accumulation of these variations can exceed the tolerance we're trying to measure.

Variability In Two-Dimensional (Contour) Measurement

The measurement of two-dimensional contours most often associated with Wire EDM adds an order of magnitude to the complexity of the task, as well as, considerable debate amongst quality professionals as to the most appropriate method to use.

Unfortunately, due to the high capital cost of contour measuring equipment, some shops will measure a few linear dimensions of a complex contour and assume that if they're within tolerance, everything else must be "OK".

You have perhaps seen examples of mating male and female Wire EDMed parts with complex contours that seem to slide together perfectly. However, whether the contours truly match over the entire contour surface, and whether the contours are within a "tenth" of nominal values, cannot be determined merely by the "feel" of a sliding fit.

Modern Geometric Dimensioning and Tolerancing (also known as True Position Dimensioning) defines the perfect contour with no accumulative tolerances, and then offers either a bilateral or unilateral tolerance zone within which the actual contour must fall in order to be acceptable. ***(See Fig# 6).***

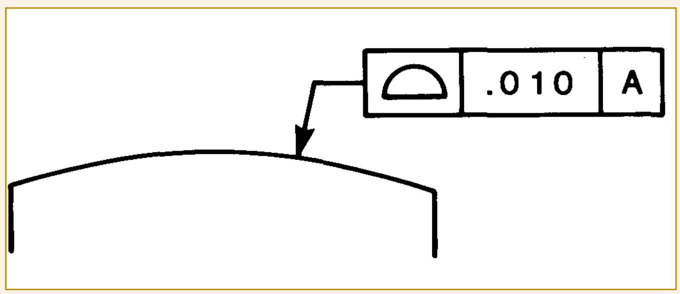


Figure 6

Therefore, contour inspection must simultaneously verify:

- Contour Position relative to a datum
- Contour Geometry
- Contour Size

The optical comparator method is an elegant solution to contour inspection, in that it gives the entire picture at a single glance: Either the contour falls within the tolerance band on the chart ***(See Fig# 7)*** or it doesn't. However, the optical comparator method can have significant shortcomings:

- For the entire contour to fit on the screen, often the magnification has to be reduced to the point that the resolution is insufficient to verify "tenth" tolerances.

- If the magnification is increased, then only individual geometry elements can be verified without inspecting their relationship to the contour as a whole.
- The position of the contour relative to a datum is often not verifiable, due to limited comparator measuring range.

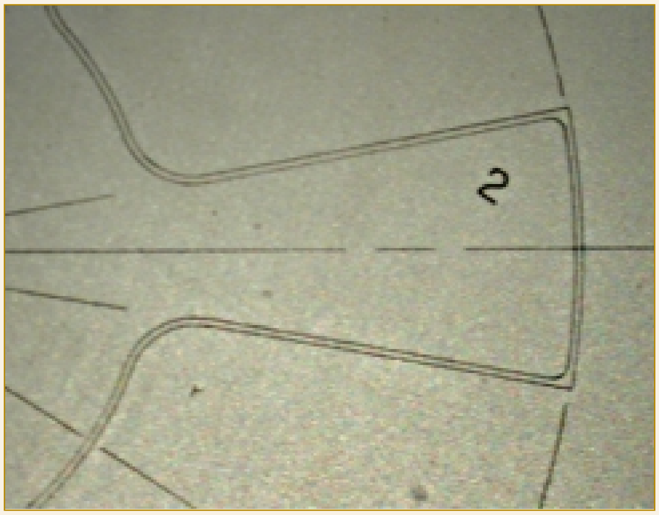


Figure 7

The components of variability of optical comparator contour measurement include:
- Magnification accuracy
- Magnification linearity
- Chart accuracy
- Chart line width
- Comparator mechanical accuracy (Similar to machine tool accuracy as discussed in Part 1 of this series)
- Surface roughness of the contour
- Taper of the contour (Since a comparator focuses only on the plane facing the lens)

Many shops utilize a CMM to inspect the contour by probing a number of discrete points on each geometry element (three points define an arc, two points define a line, etc). The major shortcoming of this method is that it is deriving the geometry from a number of selected points when, in fact, the geometry may not be true (arcs may not be truly circular and lines may not be straight). Also, since only select parts of the contour are measured, areas between the selected points that haven't been measured could be out of tolerance. Continuous CMM scans of the part surface can overcome some of these shortcomings.

The components of variability of CMM contour measurement include:
- Probe system repeatability
- Probe tip sphericity
- CMM resolution
- CMM repeatability
- CMM composite 2-D accuracy (Similar to machine tool accuracy as discussed in Part 1 of this series)
- Measuring point density
- Part set-up accuracy
- Surface roughness of the part
- Taper of the part

There are two inexpensive tests you can perform to verify the 2-D accuracy and repeatability of your CMM:
- Set up and measure a calibrated ring gage in various positions on the CMM table. Compare the diameter and roundness reported with the gage certification.
- Clamp a size block to a lab quality angle iron on an angle to the X & Y axes in various positions on the CMM table. Establish reference lines for each side of the block with multiple "hits". Using the machine's software, determine the straightness of the edges and the distance between them. Compare these observations to the size block certification.

Continuous optical and laser scanning of the part edge has also been utilized. However, it is quite possible that the edge of the contour may not be representative of the contour itself.

The most reliable method I have seen is the utilization of a CNC measuring machine in a controlled laboratory environment, performing a full contour indicator scan based upon its traversing the contour using a true position geometry program, with a strip chart recording of the indicator deviation throughout the scan.

A CNC measuring machine is essentially a super accurate two axis positioning platform with a CNC controlled, highly accurate spindle, which always keeps the indicator point on center and normal to the contour surface. With axes accurate to .00002, spindle run-out in the neighborhood of .00001, and an indicator with .00001 resolution, these machines are capable of measuring contour accuracy to within less than .00005. This is the method I was required to utilize to provide an independent inspection of jet engine Wire EDM root form (fir tree) gages, that had to be within a "tenth". Even this method has its limitations and variability:

- Inspection accuracy is only 1/2 of the tolerance to be measured.
- Internal contour features measured are limited by the size of the indicator point.
- Contour surface roughness
- Contour taper
- Flatness, squareness, and pickup accuracy of the part datum surfaces

Variability In Three-Dimensional (Surface) Measurement

The inspection of three-dimensional surfaces most often associated with Sinker EDM is the most demanding of all measurements that we have considered. The choices for effecting these measurements are limited and expensive:

- CMM with trigger probe or scanning probe
- CMM with Laser probe
- White Light optical systems

Surface measurement combines the difficulty of effecting accurate measurements in 3-D, with difficulty of depicting the results of the measurements of surfaces which are often not defined geometrically, but models from a CAD system.

The components of variability of CMM surface measurement include:

• Probe system repeatability
• Probe tip sphericity
• CMM resolution
• CMM repeatability
• CMM composite volumetric accuracy
• Measuring point density
• Part set-up accuracy
• Surface roughness of the part

Measuring point density is of crucial importance, since deviations located between measured points will go undetected. I once observed a 1/2" drill point in the middle of a large 3-D milled surface that had just been accepted by the CMM inspection department. Unfortunately, the drill point defect was between points on the measurement grid.

There are two inexpensive tests you can perform to verify the 3-D accuracy and repeatability of your CMM:

• Set up and measure a ball bearing in various positions on the CMM table. Compare the diameter and spericity with the ball bearing specifications which are readily available for each "class" of ball. (Ball bearings are incredibly accurate, low cost spheres.)
• Mount a 4" size block at a compound angle to the X, Y, & Z axes at various positions on the CMM table. Establish reference planes for each side of the block with multiple "hits". Using the machine's software, determine the flatness of the planes and the distance between the planes. Compare these to the size block's certified measurements.

The components of variability of Laser or Optical surface measurement include:

• System resolution
• System repeatability
• System volumetric accuracy
• System environment (temperature, humidity, barometric pressure)
• Surface roughness of part
• Surface reflectivity of part

The results of 3-D surface inspection are best presented in the form of a colored 3-D surface map, with colors depicting the degree of deviation from true position. This method can quickly focus attention to out-of-tolerance areas.

Variability Due To Inspector Bias

Of all the possibilities of variability in the inspection process, this is the most difficult to deal with, as it is "the Elephant in the room" that numerous shops fail to recognize.

Let's look at some common examples:

• You are measuring the diameter of 50 electrodes. The last one checks out-of-tolerance, so you re-measure it and it checks OK, so you accept it. By giving that last electrode a "second chance", you exhibited bias. If you re-checked the other 49, one or more of them might check out-of-tolerance.
• The boss is looking over your shoulder as you finish up the inspection on a $10,000 mold core that is due to be shipped out via FEDEX in 20 minutes, to an important new customer. If the part fails inspection, your company will face costly rework expenses and embarrassing delivery delays. One of the 50 measurements is .0002 out on a +/- .001 tolerance. You check it again with a little more velocity on the micrometer barrel and it just falls in. Were you biased by both implied management pressure and the cost and delay of rejecting the part?
• One of your toolmakers is inspecting a competitor's part that your company is going to rework. The part has a +/- .0001 tolerance and it is .0001 below the low limit. Even though you believe that "tenth" will not interfere with the part's fit or function, it is out-of-tolerance and the part fails inspection.
• You are inspecting one of your shop's parts with a +/- .0001 tolerance and it is .0001 below the low limit. Based upon your understanding of the part's fit and function, you "let it go". Were you biased because it was your own shop's part and not somebody else's?
• You submit a part to your customer's inspector two hours before their union contract is about to expire. Do you think it will pass? Will your shop become a victim of inspector bias? *You bet!*

Conclusion

As shop owners, engineering professionals, and craftsmen, we owe it to our customers, society, and our own personal and professional integrity, to deliver only products that meet or exceed specifications.

Hopefully, this extended treatise on EDM process and inspection variability will raise your awareness of the numerous factors that can interfere with your continued success in meeting that responsibility.

Next issue: EDM Wire Selection

Any suggestions for future topics are welcome.
Tell us what you would like to read about.
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