Where Do We Go Wrong

In Geometry Gaging?

Article Courtesy of Mahr Federal

Circular geometry gages used to be delicate, expensive devices confined to laboratories. Today, it's not unusual to find them on the shop floor, measuring parts right off a machine tool.

Several factors underlie this shift. One is improvements in gage controllers, which have made gages faster and easier to use. The second is cost. Highly capable geometry gages can be purchased under $14,000, putting them in the same price bracket with other essential quality inspection instrumentation. A third factor is ruggedness. The new generation of geometry gages has been engineered to withstand the shop floor.

The most important factor, however, is need, driven by tighter tolerances and more demanding specifications.

With the shift in location has come a shift in users as well. Formerly, most geometry gage users were specialists trained to understand part form as it related to manufacturing processes and applications. Now, the typical user is more likely a machinist measuring parts as a QA function.

Even while computer controllers have greatly simplified geometry measurement, it remains a complex field subject to many misconceptions. Gage operators must understand the meanings of various geometric parameters and be familiar with how they are indicated on part prints. Operators must understand how to set up a gage and a part and the purposes of various functions.

Most common errors in geometry gaging can be grouped into ten categories. Gage users will generate more reliable results if they bear these gage "commandments" in mind.

1. Measuring the wrong parameter

Many geometry parameters that seem self-evident are not.

In the world of simple indicator gaging, the terms "runout" and "out-of-roundness" are occasionally used interchangeably. But they are not, in fact, the same, and must be measured differently. Likewise, when gaging perpendicularity, parallelism, and some other parameters involving the relationship between two surfaces, the user must understand which surface to measure first.

For example, in geometry specifications that appear on part prints, the statement "B is parallel to A" is not equivalent to "A is parallel to B." By definition, the second surface in the statement is considered to be the reference, or datum. Out-of-straightness, or circular out-of-flatness, are ignored on that datum surface but are relevant to the other surface.

All of these parameters, in addition to circularity, concentricity, coaxiality, and others, are defined in the ANSI Y14.5M standard.

Y14.5M also establishes a standard set of symbols for indicating geometric specifications in part print callouts.

2. Poor clamping arrangements

How a part is staged on a turntable can have an influence on measurements. The common three-jaw chuck can deform thin-walled parts so they appear to have a

three-lobed condition when gaged. Tall, narrow parts may need special clamping for stability, while heavy parts may need no clamping at all.

3. Inattention to centering and leveling

Centering and leveling are critical elements of a gage setup procedure. A round part that is not level will produce an oval measurement trace, while one that is significantly off-center on a spindle will produce a vaguely heart-shaped trace. Even if a gage turntable is equipped with a holding fixture for a particular part, an operator should run a centering and leveling program before measuring.

4. Datum problems

Some parameters do not require that a datum be established on a part: a part's profile is compared to a gage spindle's axis of rotation. Other parameters, however, are measured relative to a datum surface or to an axis representing another element on a part. In these cases, establishing the datum is the first step in taking the measurement.

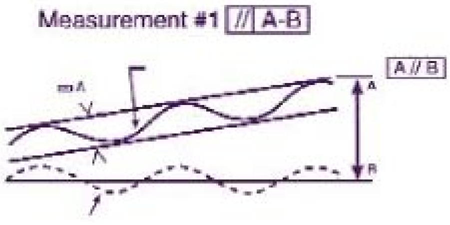
A part print may specify a tolerance for a geometric relationship between features and fail to specify which feature or features should be used to establish a datum. Ideally, a part designer should select a datum, but designers are not always aware of the capabilities or limitations of geometry gaging systems. Specifications are then written that are unmeasurable in practice.

5. Risky reliance on filter default values

Any geometry measurement exhibits variation resulting from several influences. A part's true form is influenced by variables in the manufacturing process, including clamping and tool chatter. Added to these are variables introduced by the measuring process itself, including setup accuracy, part clamping on the turntable, and environmental influences.

Each influence produces a pattern of undulations on the trace of the part surface that the gage generates. Bad leveling will make a part appear to have a two-lobed condition. The dynamics of the centerless grinding process typically impose an odd number of undulations per revolution (UPR) of the part--often five or seven. Bearing vibration in the machine tool spindle might add a larger number of undulations.

Geometry gages incorporate electronic filters to simplify the trace by eliminating undulations that appear outside certain desired frequency bands.



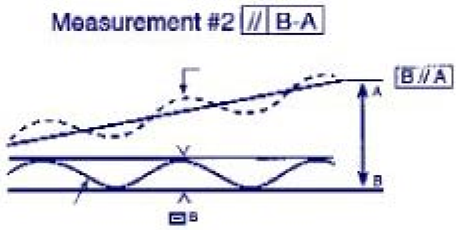
One can choose to generate a trace that only shows undulations that occur between zero and 15 times per revolution. This trace reveals low frequency errors due mostly to clamping and setup factors. Or, one might choose to filter out only frequencies above 125 UPR to include the results of more dynamic factors in the analysis.

The ANSI B89.3.1 standard establishes 50 UPR as a default value for measurements of out-of-roundness. When a 50-UPR filter is engaged, undulations that occur at frequencies above 50 UPR are filtered out. Use of this filter is appropriate for many, but not all, applications.

Some rotating parts may produce undesirable noise if higher-frequency undulations exceed certain amplitudes, so it may be necessary to filter gaged data for up to 150 or 500 UPR or even to analyze gage data without electronic filtering. A part designer should define the frequency filter to be used, based on the functional needs of the application.

6. Using the wrong stylus tip

Many geometry gage users rely upon a single stylus tip for all measurements, regardless of the size of the part they are gaging. But the stylus tip represents a mechanical "filter" that must be selected according to part diameter and the maximum number of undulations per revolution relative to the application.



If a tip radius is too large, it will bridge over small irregularities. Larger tips will exert less pressure against a part, which may be a concern when measuring very sensitive surfaces. New ANSI and ISO draft standards specify stylus tip radius as a function of both part diameter and number of undulations per revolution that can be measured.

7. Using the wrong reference circle

Out-of-roundness is measured by comparing profile irregularities to a gage spindle's axis of rotation by means of one of the following four reference circles: the Maximum Inscribed Circle (MIC), Minimum Circumscribed Circle (MCC), Least Squares Circle (LSC), and the Minimal Radial Separation (MRS) Method. All four methods are described in ANSI B89.3.1. Results generated by these four approaches can differ by as much as 10-15 percent when evaluating the same profile.

The earliest geometry gages typically used the MRS reference circle. Gages of more recent vintage, produced into the early 1990s, employed the LSC method, relying upon computers to perform more complex calculations.

Today, PC-driven geometry gages offer all four methods. Part designers should specify the method best suited to the application.

8. Confusion over scaling effect

The trace of a roundness measurement, as shown on a gage's computer screen or on a chart print-out, rarely looks "round." It usually looks like a mass of sharp peaks and valleys. This can distress users who believe that the chart shows terrible part geometry.

A gage applies a different level of magnification to the size of a part than it applies to a deviation from the ideal geometry being measured. To permit the operator to see an error of 0.0001" on a part with a 1" dia., a computer has to magnify an error by 1,000X or more. But if an entire part profile were to be magnified by the same 1,000X, a screen would have to be more than 80 ft. high!

The solution provided by gage manufacturers has been to normalize the part dimension to a fixed-size circle on a screen. This may involve a low level of magnification for small parts or even a reduction in scale for large parts. Deviation is highly magnified, from 1,000X to 20,000X or more.

Geometry gages allow a user to select a magnification level. Even though the computer's trace does not accurately depict the part's actual profile, the relationship between peak heights and valley depths remains consistent with the level of magnification chosen. Peaks and valleys also retain accurate angular relationships to one another around the circumference.

9. Choosing the wrong type of signal processing filter

The original filters used in geometry measurements--known as "2RC" (double resistor-capacitor) filters--were designed before the age of digital electronics. When computers were applied in geometry gaging applications, new digital filters were designed to simulate the response of the analog devices to generate results consistent with those from earlier gages. These quasi-analog filters, still in use, are referred to as 2RC filters.

The newest geometry gages incorporate 50 percent Gaussian filters that use true digital signal processing methods. (Gaussian refers to the bell-curve shape of the processed signal; the 50 percent figure refers to the amplitude cutoff.) These new filters are more accurate than 2RC filters and create less signal distortion.

New standards soon to be published by ANSI will probably permit the use of both types of filters, while new ISO-based standards will only allow Gaussian filtering. Depending upon the standards adhered to, some companies may be forced to purchase equipment or upgrade existing systems to incorporate Gaussian filters.

10. Ignoring advanced gage functions

Advanced metrology software can tell a user much more than simply whether a part is within tolerance. While simply isolating bad parts may be a worthwhile task in some applications, skilled QA technicians can subject parts to more in-depth analysis to find out what is wrong in a production process, to identify ways to correct it, and to predict the performance of a "bad" part if it is installed.

Slope analysis is an advanced analysis feature included in some geometry gaging software. In part geometry, "slope" is the rate of change of the radius with respect to the angle of rotation. The maximum difference between the longest and the shortest radius on a roundness trace (measured out-of-roundness) might be "X" for a given part.

If the longest and shortest radii occur within just a few degrees of rotation of one another, the slope connecting the two points on the circumference will be steep. On the other hand, if the longest and shortest radii occur diametrically opposite one another, the slope will be gradual. A given amount of out-of-roundness might be acceptable in some applications where the slope is gradual but unacceptable if the slope is steep.

Harmonic analysis is an advanced feature available in some geometry software that allows analysis of individual, predominant numbers of undulations per revolution. While filtering techniques allow a user to view the effect on out-of-roundness of several undulations within a relatively broad frequency, harmonic analysis allows a user to focus on a single harmonic or frequency.

Another advanced feature of new shop-floor geometry gages is artificial intelligence (AI). AI enables a gage to recommend appropriate analytical methods to find the source of errors, reducing the expertise level required of an operator.

Yet the very high degree of sophistication in geometry gages that allows a diminished expertise level of an operator still requires a user's sound understanding of a gage's capabilities and limitations to obtain optimum results.

Geometry gaging can help manufacturers improve the quality and functionality of their designs, but as with any good tool, some investment in training is required to reap the rewards.