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METROLOGY INSIGHT

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Welcome to this first edition of Metrology Insight published by HN Metrology Consulting. The purpose of Metrology Insight is to heighten the awareness of the details that go into making good metrology and, of course, HN Metrology Consulting as a source of information about these details.

There are two articles in this issue. One on creating correlation in form measurements and one on the advantages of using uncertainty budgets.

I hope you find Metrology Insight useful and educational. If you have a suggestion for a topic or any other comment or suggestion, please do not hesitate to contact me.

S Henrik Nielsen

Achieving Correlation in Form Measurement

There are many different types of instruments available for measuring form, i.e. roundness, straightness, flatness and cylindricity.

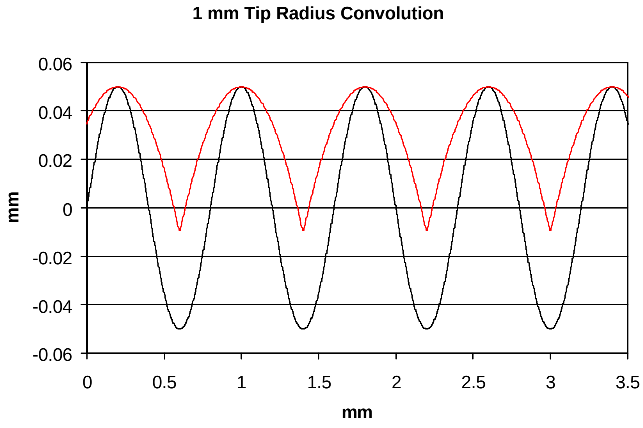


Figure 1: The distortion of a sinewave with 0.8 mm wavelength and 0.1 mm peak-to-peak amplitude, when traced with a 1 mm tip radius.

Most of these instruments even have several parameters, that need to be set, such as tip radius and filters, so it seems almost impossible to make them all agree.

The trick to making the instruments agree, is to understand what makes their results different. If we look at a simple sinewave in a surface and see what happens when we use different tip radii to measure the form of that surface, we find that different radii cause different distortions of the surface as seen by the instrument.

If we compare figures 1 and 2, we see the difference between a 1 mm and a 0.25 mm tip radius for the same surface profile. This distortion is the reason that instruments using different tip radii do not agree. In the specific case, the peak-to-valley distance is reduced from 0.1 mm to 0.06 mm, when the 1 mm tip radius is used. The difference may be smaller or larger, depending on the surface and the difference in tip radii.

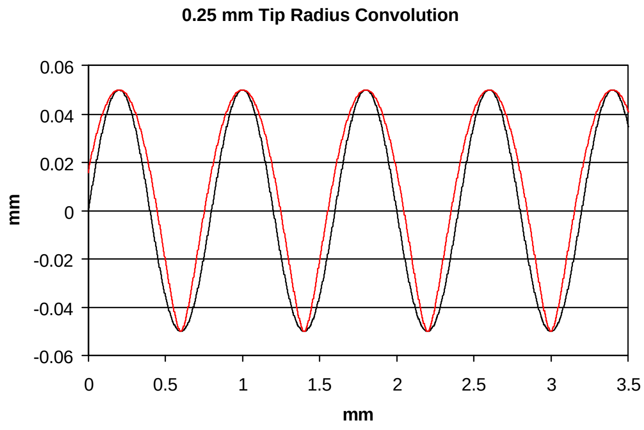


Figure 2: The distortion of a sinewave with 0.8 mm wavelength and 0.1 mm peak-to-peak amplitude, when traced with a 0.25 mm tip radius.

Some instruments digitize the surface profile into discreet data points. Others work directly with the analog signal from the probe tip. For the digitizing instruments, the number of points collected will influence the measured value, but it is easy to overlook the fact that even an analog instrument has a bandwidth that limits how fine a surface feature it can resolve.

Once the surface has been traced, some instruments filter the data to eliminate the effects of roughness and other short-wave phenomena that are not considered part of the form deviation. This, of course, leads to differences, not only between filtering and non-filtering instruments, but also amongst filtering instruments using different types of filters and different filter cut-off settings.

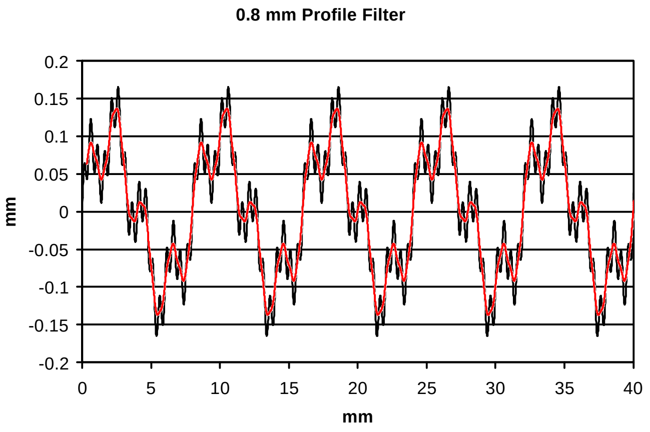


Figure 3: *A surface profile before and after application of a profile filter with a 0.8 mm cut off.*

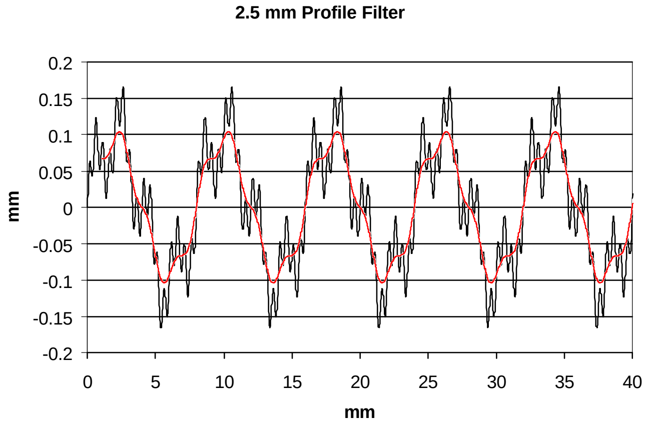


Figure 4: *The same surface profile as in figure 3, but with a profile filter with a 2.5 mm cut off applied.*

Figures 3 and 4 show the change that occurs, when different cut-off values are used. For the 0.8 mm cut-off in figure 3, the peak-to-valley amplitude after filtering is 0.26 mm, whereas it is only 0.2 mm for the 2.5 mm cut-off used in figure 4.

Once we understand these differences and their origin, we can achieve correlation by making sure we always use identical settings for the same kind of surfaces across all the instruments we want to correlate. When we do that, we can compare measurements from Surface Finish Instruments, Form Measuring Machines and even Coordinate Measuring Machines. Depending on our situation, we may even be able to make dial indicator type measurements correlate.

So how do we know what is important and how do we choose the values that are right in our situation?

The easiest way to do it short term is to establish a company standard for how form tolerances are interpreted and how they are to be measured, not in terms of brand and model of instrument, but in terms of the important instrument parameters. The primary ones are:

S Probe tip radius
S Filter type and setting
S Data density

To make sure that everything relevant is pinned down, it is generally a good idea to conduct a correlation study across the different types of instruments that will be used.

However, there is help on the way from the standards community. Both ISO and ANSI/ASME are working on standards for form measurement. ISO is about to release standards for all 4 types (roundness, straightness, flatness and cylindricity) within the next year or so and ANSI/ASME is getting ready with a roundness standard - and they even agree!

These standards define the default settings for all relevant instrument parameters necessary to achieve correlation. But what if these standard settings are not right for the part function we are trying to control? That is the next stage of increased versatility in form specification and measurement.

To get to this stage, we need to give the designer the tools in the design standard to indicate that he wants different instrument settings than the default, either because he wants more or less of the finer structure of the surface included in the assessment.

Correlation is not difficult to achieve. All it takes is some methodical work to pin down the pertinent parameters. Once that is done, correlation happens more or less automatically and we can use whatever instrument is most convenient for our measuring task, as long as we keep all the important parameters constant.

The Benefits of Estimating Measurement Uncertainty

Estimating measurement uncertainty is becoming more and more of a required activity in metrology laboratories. It is increasingly difficult to get by with 10:1 rules and GR&R (Gage Repeatability and Reproducibility) studies alone.

But instead of seeing this as an unnecessary, extra work burden, it should be seen as a tool to make work in the laboratory more effective and to optimize the cost and effort involved in measurement - here is how:

If we design our measurement processes without conscious regard for the uncertainty budget, it is inevitable that we do some things in ways that are too cumbersome and too expensive for our purpose. On the other hand, it is equally inevitable that there are some things we are not controlling as tightly as we should, e.g. the environmental conditions, or that we are just overlooking in the design of our measurement processes.

An uncertainty budget is a formal way of documenting the factors that influence the outcome of our measurements and their relative magnitude. So when we make an uncertainty budget for a measuring process, we learn what the big hitters are. Often it is surprising to learn what is really important and what is not, but until we set up the uncertainty budget, we can only guess.

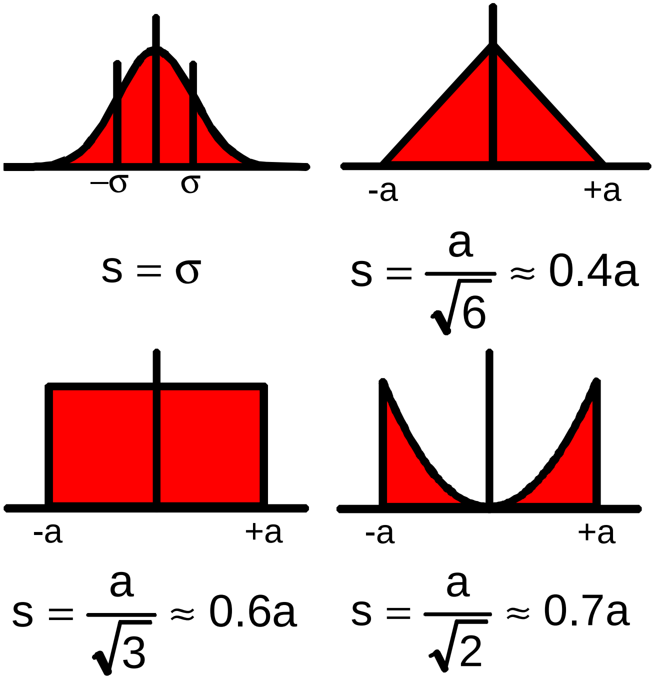
If, for example, we are looking at buying a new CMM (Coordinate Measuring Machine), we need to know what the right environmental enclosure is. How tightly do we need to control temperature in order for the machine to live up to its specification on real parts? An uncertainty budget can answer not only that question, but also how long we need to soak the parts in the enclosure to equalize temperature before we can expect to be able to measure them to the tolerances we need. Without an uncertainty budget, all this is guesswork.

Another example is calibration of simple, handheld gages. What should we be calibrating? To what tolerances? If we know how the gages are going to be used and have uncertainty budgets for their usage, the calibration procedure practically writes itself. We simply take all the requirements from the measurement processes where the gage is used and the sum total of those are the calibration requirements. Often we will find that some features of the gages are calibrated much too well and others (which turn out to be important) were totally overlooked.

But isn't it difficult to develop an uncertainty budget? Not necessarily. There are simple methods available, that work well for the majority of measurement processes in any field or industry.

These methods can be successfully applied by anybody who is comfortable using square roots and who has a basic understanding of the physics governing the types of measurements in question.

The Four Most Commonly Used Distributions for Estimating Equivalent Standard Deviation



$$s = \sigma$$

$$s = \frac{a}{\sqrt{6}} \approx 0.4a$$

$$s = \frac{a}{\sqrt{3}} \approx 0.6a$$

$$s = \frac{a}{\sqrt{2}} \approx 0.7a$$

For the normal distribution, the equivalent standard deviation is equal to σ of the distribution. For each of the others, the triangular, the rectangular and the U-shaped, the formula gives the relationship between the variation limits +/- a and the equivalent standard deviation, s.

A surprising level of accuracy can be achieved by just using engineering judgment to estimate limits of variation of e.g. temperature, measuring force, runout, and guideway straightness and squareness.

A simple set of equations (see figures above) exist to translate these limits of variation - based on their distribution - into *equivalent standard deviation*, the "currency" used to combine uncertainty contributors.

Once all the contributors are translated into equivalent standard deviations, they can be combined using the square root of the sum of the squares of all uncorrelated contributors. Correlated contributors have to be added together linearly in advance.

Finally, the *combined standard deviation* is multiplied by a *coverage factor*, typically with a value of 2, to get an uncertainty interval which covers a substantial part of the error distribution, typically no less than 95 %.

With these simple calculations, it is possible to get a very good understanding of the uncertainty of a measuring process. The estimate will not necessarily be very accurate, but it will identify the major contributors.

Once we know the major contributors, we know that those are the ones we need to reduce in order to reduce the overall uncertainty of the measuring process.

On the other hand, if there is any minor contributor where we can save money by relaxing the tolerances, we know that we can do that without increasing the overall uncertainty of the measuring process.

I hope this short article has provided some insight into the advantages of using uncertainty budgets, by showing what a powerful tool an uncertainty budget is in managing measurement processes.

Training from HN Metrology Consulting:

Managing Measurement Uncertainty
November 9-10 1998, San Diego, CA.

Register before October 15

In this 2 day training seminar you will learn how to use uncertainty budgets to manage your measurement processes as outlined in this issue of Metrology Insight.

The seminar is targeted at all personnel involved in managing measurement processes in any industry or field of metrology and personnel using measurement results in decision making.

The following is an excerpt from the seminar brochure:

"Managing Measurement Uncertainty is a basic activity in measurement laboratories and on production lines in modern industry. ISO 9000 and the new edition of QS 9000 has put increased focus on this issue. Accounting for the measurement uncertainty is also a prerequisite for a calibration laboratory to gain accreditation to ISO Guide 25.

The training seminar also teaches the use of uncertainty budgets to optimize measurement processes in terms of uncertainty and cost. This is a very powerful aspect of the seminar, that can lead to significant savings."

Contact HN Metrology Consulting for more information on this seminar and to request the brochure.

ISO TC 213: Geometrical Product Specifications

This is the standards committee responsible for the form measurement standards. However, the scope for the committee is much broader than just form measurement. You can find more information at the TC 213 web site:

http://129.142.8.149/isotc213/index.htm

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