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IMPROVING YOUR MANUFACTURING PROCESS

QUALITY SPENDING SEES HOT SPOTS p. 20

50 YEARS OF *QUALITY*: CIRCLING BACK ON CALIBRATION p. 18

NO-COMPROMISE LEADERSHIP HELPS COMPANIES SURVIVE AND THRIVE p. 26

TOTAL QUALITY MANAGEMENT IS NOT TOTAL p. 30

NEW COLUMN: LEGAL INSIGHT p. 15

INSIDE THIS ISSUE

Sensors

Inertial Sensor Components

Achieving Higher Mechanical Precision with Profile Tolerancing

by

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Today's design, manufacturing and quality engineers are faced with the seemingly impossible task of clearly communicating the increasing complexity of surface geometries. The challenge is heightened by the simultaneous reduction in feature tolerances needed to meet reduced size, weight, cost, and time to market targets. These trends are driving the need for unprecedented precision in all technical disciplines. Precision GD&T featuring the use of profile tolerancing is emerging as the key solution for dimensioning and tolerancing practices for mechanical and electro-mechanical components and assemblies.

Figure 1 is a gyroscope housing that represents typical complex surface geometries. The features on this part represent a collection of small arc radii and are used within this article to demonstrate the tremendous value and precision of profile tolerancing.

Figure 1 – Gyroscope Housing

Global Tolerancing Transformation

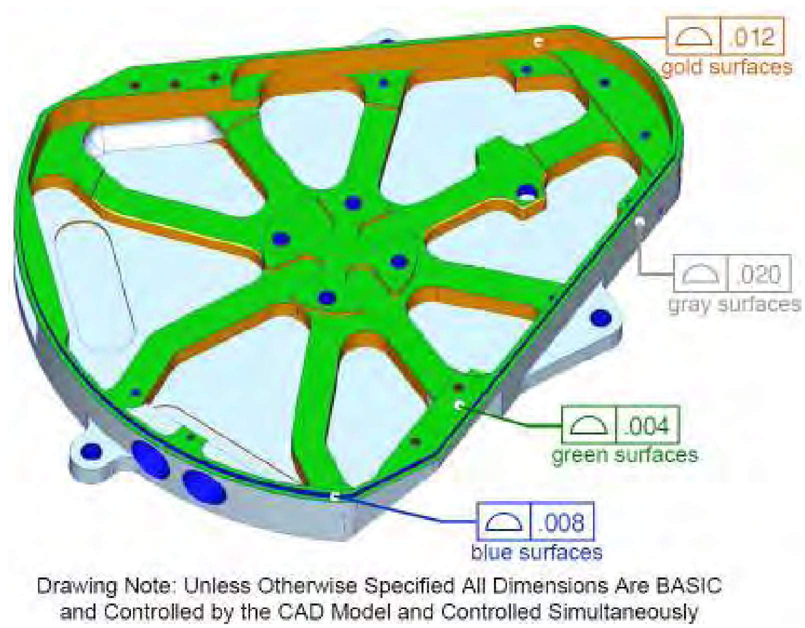
Designers' expectations dictate that all variations on the surfaces of their component parts lie simultaneously within a uniform boundary. While the allowable variation of these boundaries, also known as tolerance zones, might vary from one surface or set of surfaces to another, they are all still expected to meet those requirements. The application of profile tolerancing precisely conveys true design intent and provides a robust solution that significantly improves precision measurement in manufacturing and metrology, and also significantly reduces costs and lead times. **Figures 2 thru 6** show an optimized sequence of deliverables and activities to ultimately achieve desired goals in mechanical design definition, precision measurement and process capability.

The precision language of profile tolerancing is explicitly defined in the ASME Y14.5M-1994 Standard and mathematically complemented by the ASME Y14.5.1M-1994 Standard. Both of these Standards form the basis for precise definition of complex surface boundaries and should be the basis for 3D tolerance analysis for designers and also for 3D precision measurement analysis for physical metrologists.

Designers must specify all requirements through a precise engineering language and communicate these requirements through a mechanical drawing or electronically through the 3D CAD model and a minimally dimensioned drawing per ASME Y14.41-2003, Digital Product Definition Data Practices.

Figure 2 shows an engineering drawing example that depicts profile tolerancing of all 3D surfaces being fully defined with four explicit profile callouts per the ASME Y14.41-2003 Standard. There is no need to show dimensions on the drawings as they are embedded in the CAD model and directly available to manufacturing, quality and other applicable disciplines.

Figure 2 – 3D Engineering Drawing Example per ASME Y14.41-2003



Once specification requirements are documented effectively by the designer, it is expected that manufacturing and quality engineers will be able to interpret these engineering requirements precisely to manufacture and inspect component parts to ensure compliance with all requirements. Ideally, this communication is accomplished using the same optimized CAD model so additional errors are not propagated throughout manufacturing and quality. An optimized tolerance model results in smooth transitions between individual adjacent features.

As design and manufacturing require highly confident measurement data to make technical and business decisions, it is essential we focus some attention on precision measurement and what it takes to provide precise results. Precision lost on the product specification and measurement side will have to be compensated by using more accurate machine tools to reduce variation. This will be more expensive than educating engineers about the principles of GD&T and measurement uncertainty.

Precision Measurement Technology

Historically, metrologists have found measurement of profile tolerancing too complex due to coordinate measuring machine (CMM) software limitations. Today, profile tolerancing is considered one of the simplest ways to analyze complex surface geometries, as long as the users have the applicable software. The software used to complete this analysis is SmartProfile™ by Kotem Technologies.

Figure 3 represents a set of measured points, each having an associated X, Y and Z value, which are then used in the calculations for profile. One of the most common uncertainty contributors can be influenced by how many points are measured by the metrologist. The higher the point density the higher the confidence will be in the measured results. The CMM can simply be considered the "point collector" so all the metrologist needs to do is to save the point array as a text file or other file format. Once complete it is available to be imported into SmartProfile.

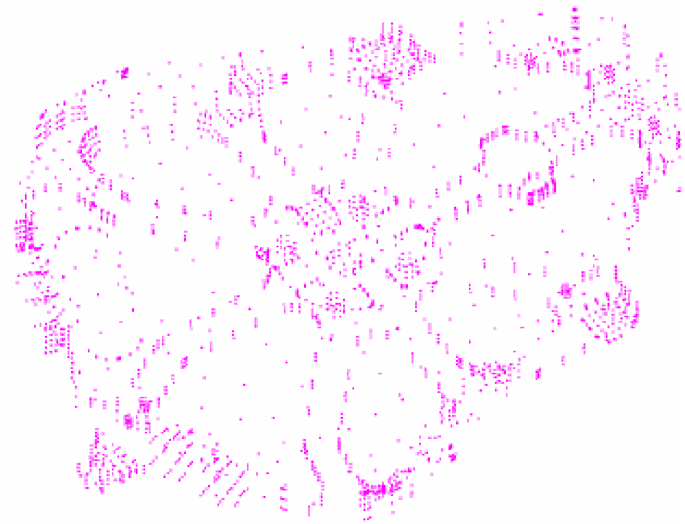


Figure 3 – Measured Point Array

Figure 4 represents the measured point array integrated with the CAD model into SmartProfile which is then used to analyze the results.

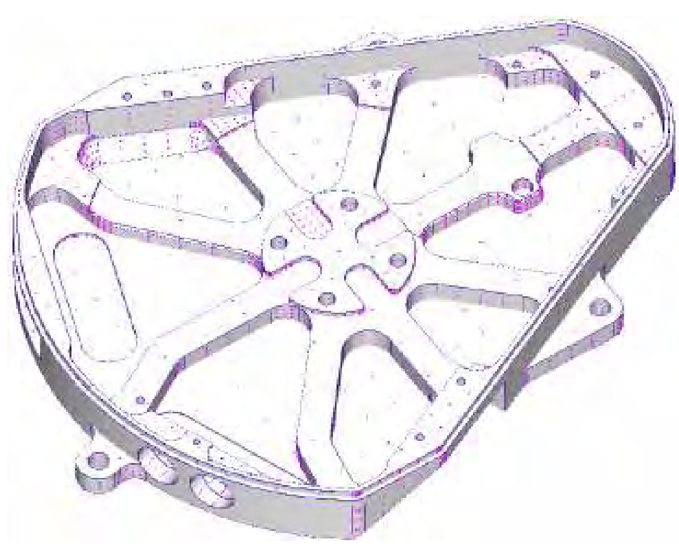


Figure 4 – Combined CAD Model and Measured Point Array

Figure 5 shows the graphical output of the profile analysis within SmartProfile. The color-coded surface profiles are shown as a topographical map and quickly communicate compliance or non-compliance to the specified tolerance. The software integrates a color bar graph showing percentage of tolerance used as associated with each of the individual tolerances, so users can quickly analyze the true magnitude of variation on each of the surfaces in the minus and plus material directions.

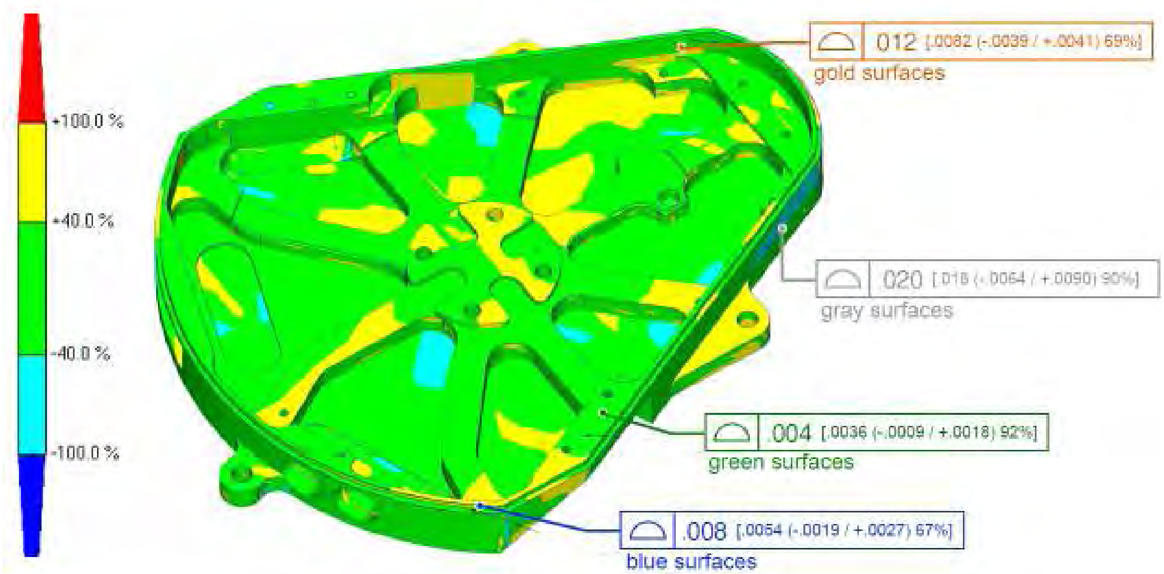


Figure 5 - Profile Tolerancing Showing Deviations as Percentage of Applicable Tolerance

Out of tolerance conditions can be seen in the expanded feature control frames via the additional information shown in brackets. The first value in brackets is the value that is compared directly to the specification requirement, which is the first indication of compliance or non-compliance to the specification requirement. If the value is less than the specification requirement then it is in compliance. The second and third values in the brackets (shown in parentheses) indicate the worst-case deviation in the minus and plus material directions. The fourth value in the brackets indicates the percentage of the specification tolerance used, which is valuable to manufacturing and quality as it is a quick indicator of how good the process is operating.

The graphical information allows all engineering functions to immediately see effects resulting from the manufacturing process, and provides indications on how to optimize the process to achieve better results. If the manufacturing engineers cannot see the variation, then process optimization is much more difficult.

Figure 6 shows the graphical output of profile tolerancing as absolute deviations based on the worst-case range of results. The color-coded topographical map quickly communicates to the user the true magnitude of variation on each of the surfaces throughout the entire range of results.

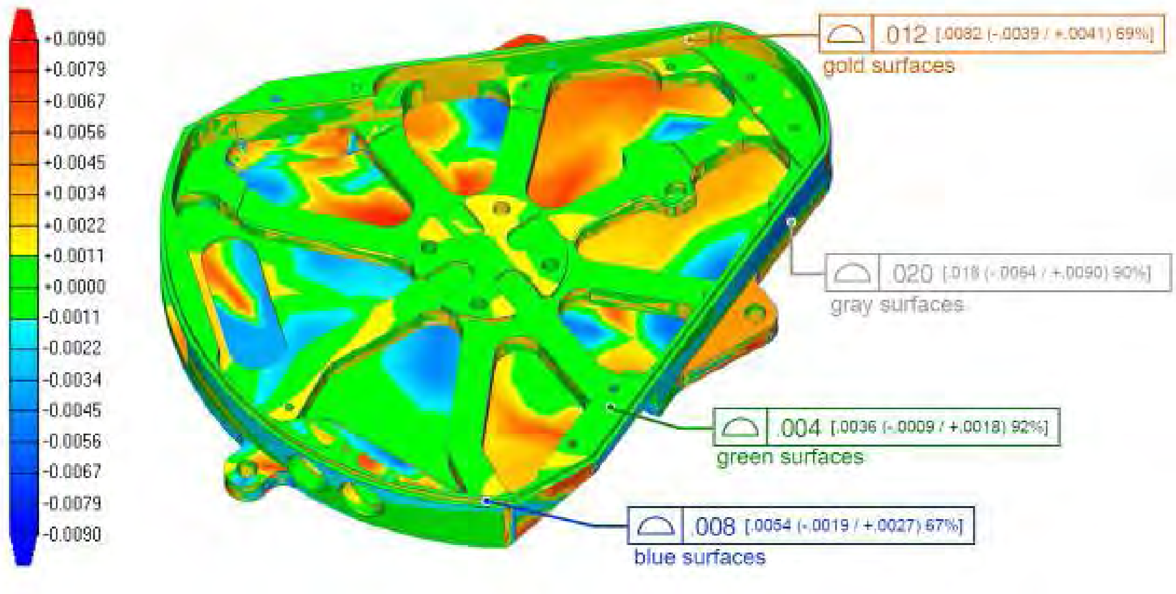


Figure 6 - Profile Tolerancing Showing Actual Deviations

Profile analysis software, such as SmartProfile, makes complex profile analysis much simpler than ever before. It can also solve software validation efforts on every metrology software package, as many companies are not capable of analyzing results to the ASME Y14.5.1 Math Standard. Software validation can be reduced to one core software that can be used no matter which type of CMM users have. Supplier engineers, development engineers and others can simply request the measured point array from the metrologist and analyze the results in minutes rather than rely on confusing inspection reports. Profile analysis software also assures evaluation uniformity within the whole manufacturing process no matter how and on what measuring device the raw data was collected.

Questions for OEMs and Suppliers

The following are questions you can ask to ensure both OEMs and suppliers are committed to achieving precision GD&T through the use of profile tolerancing:

1. Are both parties working together to define and understand areas of weakness within current designs, manufacturing process, and measurement processes to optimize upon future product and process platforms?
2. Are all critical team members trained in precision GD&T to the degree necessary to perform their respective tasks?
3. Are designers precisely defining their true design intent on engineering drawings by specifying surface geometries using profile tolerancing?
4. Do OEMs and suppliers have adequate software to complete optimum measurement analysis at the metrology level per the ASME Y14.5M-1994 and ASME Y14.5.1M-1994 Standards?

Conclusion

Within the last decade the problems associated with linear tolerancing are becoming more visible within design engineering groups. Miniaturization of components and reduction in feature tolerances make it essential that components and assemblies are defined with precision GD&T using profile tolerancing to ensure functional intent of the design is truly met. This precision language, when supported by optimum manufacturing equipment, precision measurement system, capable analytical software, and competent, well trained individuals, will allow OEMs and suppliers to meet their goals.

A commitment to precision GD&T using profile tolerancing and other key geometric controls is essential for establishing a true partnership between OEMs and suppliers. Only by investing in and committing to precision GD&T can both parties experience its full benefits – clear communication of design intent, reduced measurement error, lower costs, faster time to market, and ultimately, higher profit.

To review the full article see:
http://iigdt.com/Products/Seminars/pdf/Profile_Article_in_Quality_Magazine.pdf

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