The industrial world is continuing its adoption of Geometric Dimensioning and Tolerancing (GD&T), the advanced tolerancing methodology. The symbolic language is intended to be both more precise while providing more latitude in allowable variations, replacing the simpler method of adding tolerances to each dimension. “Basically GD&T is a language of symbology,” explained Rob Jensen, Dimensional Standards Compliance Manager of Hexagon Metrology (North Kingstown, RI). Each of its 14 symbols has a unique purpose and definition, specified in a ‘feature control frame’ with specific modifiers and datum references. Like a language, the grammar that ties the symbols GD&T and modifiers together is important. Measurement and quality programs need to use GD&T to measure parts and ensure they meet design intent.

With a well-defined language, a designer or manufacturer should interpret each feature control frame the same. However, that is usually the problem.

“People in different areas will look at the same drawing and the same call out and interpret it differently—and measure it based on their interpretation,” said Jensen. “That will yield
a different result." As Jensen describes it, there have always been issues in communicating design intent. In the past, when designers and manufacturing were in the same company—often in the same building—informal communication served them well. Companies could pass on the traditions of practice that he describes as tribal knowledge. Companies used tribal knowledge to manufacture quality goods with drawings or CAD data that were incomplete in terms of design intent.

As supply chains grow ever more complex it is imperative to have design data that is complete in and of itself. Interpretation cannot vary. “That has become a real problem with the global market, as companies now are designing in one location and subcontracting the manufacture in another location. The communication is now what is strictly on the drawing,” he explained. “The drawing needs to be correct and people reading the drawing need to be able to interpret GD&T consistently around the world.”

Two separate standards define the languages of GD&T and are not the same. One is the North American standard, Dimensioning and Tolerancing, ASME Y14.5-2009. The international standard is ISO 1101:2012. Each drawing or CAD model (or both) needs to state the standard it uses.

Interpretation ideally would follow by simply looking up the standard. “You would think reading the standard should be enough, but I think the standards as written can be difficult to understand,” said Jensen. He believes proper training of design engineers, manufacturing, and quality professionals is required to fully solve the problem. “I see more training with manufacturing and inspection people, not as much at the engineering level. But it begins at the design engineer” whose training is vital, since they are the ones who need to specify GD&T properly on the drawing, according to him.

There are software aids. “Our software, PC-DMIS, has been designed to interpret GD&T,” he said. If the Feature Control Frames do not comply with ASME Y14.5 or ISO 1101, the software can detect these errors and report them. More companies are embedding aids and tools for GD&T interpretation, but that can only be a part of a solution.

**Different Standards, Balancing Cost**

An important point for global supply chains is which standard to choose. “GD&T is a pretty hot topic right now and there is a lot of energy, both internationally and in the US, as to what does it mean to measure GD&T,” said James Salsbury, Corporate Metrologist for Mitutoyo (Aurora, IL). One of the issues he points out is that the ASME Y14.5 and ISO 1101 standards have diverged in their most recent releases. “Some people assume they are the same and they are not,” he said, a difference that has become more pronounced. “Today, the difference is huge; [with experts saying that] only 10 to 20% of the symbols have the same meaning.”

While using the same symbol and even the same word, such as circularity or true position “they differ at their core,” in how those quantities are defined, Salsbury said. “The US standard hasn’t changed much, but the international standard has a lot of new ideas, a lot of new thinking, and it’s beating down a path at a very fast rate, changing the fundamental rules that apply,” he said.

With either standard, when interpreted correctly, the ideal result is a measuring program that not only accounts for the GD&T on the drawing, but the business needs of the organization. “The measurement process should be designed to balance measurement quality and cost,” explains Salsbury.

**Scanning metrology systems that produce color maps of deviations may in some instances be just as useful as GD&T.**

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“No measurement process is perfect, but [it can be useful] as long as the uncertainty in the process is acceptable and balances out against the cost.” That is the key issue in dimensional measurement planning, converting design intent and GD&T specifications into a cost-effective measurement plan. Plenty of choices are available to metrologists. That includes hardware such as choosing a CMM over a micrometer or selecting a least squares fitting algorithm to measure hole diameter and circularity.

Practicalities and Point Clouds

“One of the toughest things with GD&T is interpretation,” agrees Josh Old, applications engineer with Capture 3D (Farmington Hills, MI). “About 20% of the problems I deal with are GD&T issues.” When asked to look at a print that someone is having difficulty using, it is sometimes obvious that the originating engineer lacked experience and knowledge in GD&T. Issues include not properly setting datums or the more complicated functionalities. Some of these issues may also be the nature of the parts they work with. Capture 3D specializes in offering metrology equipment from German supplier GOM, including ATOS blue light scanning equipment and the TRITOP hand-held photogrammetry system. Blue light scanning is used for various part geometries from simple, organic, to complex—from the grooves on a fingerprint to the leading and trailing edges on an airfoil. “Nothing is square on them,” explained Old. “So, they have to manufacture something on them that is square. Or, they have to figure out a way with GD&T and setting datums to get the quality measurements they need out of it—that is sometimes very complex.” He notes that the profile feature is important when scanning is used for the measurement. Profile lines or surfaces are two of the thirteen specific characteristics in either GD&T standard.

Disagreements are common. “I have been in rooms where two engineers from the same company have disparities on how to interpret just one call out,” said Old.

He also believes that GD&T as a language is especially important for building assemblies. “For example, when aligning holes to ensure components will mate when assembled,” he said. “They use GD&T for inspection to ensure that mating.”
However, he notes that with scanning technology, such as the full-field ATOS that delivers millions of points over a surface, ATOS software also offers color map comparisons. This is done by importing scan data as a cloud of points to create color maps to highlight deviations from the CAD nominal. Users align that information any way they wish to understand assembly mating—and design intent. “More people are going towards color mapping [instead of GD&T] because they can get a full-field profile across the entire part, and then change the alignment any time they want to,” he said. Still, he said that many keep relying on GD&T call outs and creating measurement programs to check them.

Another approach to interpreting scan data is to import it as point cloud data into a program that would then extract features, simulating the operation of a virtual CMM.

That is what the newest version of Metrolog software from Metrologic (Wixom, MI) does. Metrolog X4 for CMMs was released July 2014, according to applications engineer Gerry Stevenson. Using point cloud data as a data set for interpretation makes sense, since the purpose of Metrolog is to act as a single interface for all metrology devices, from portable arms to CMMs. “Metrologic has developed more than 60 direct machine interfaces to connect its software to any controller including CNC CMMs, articulated arms, laser trackers and 3D optical Scanners,” explained Stevenson. “That means all of the GD&T protocols we have work with point cloud or touch probe.”

This minimizes the impact on the customer, according to him. “Our customers do not have to be GD&T gurus, because using the advanced option in Metrolog will guide the user,” said Stevenson. “They have to follow the standard and cannot deviate from it,” which can be either ASME Y14.5 or ISO 1101.

The challenge of incorrectly applied GD&T at the source remains, he acknowledges. He also sees a range of expertise
Software that flags errors in GD&T descriptions aids professionals in understanding the language better.

in Metrolog users, from some who are proficient to others who have never been exposed to it. “The purpose of Metrolog is to guide them through it so they do not do something illegal according to the standard,” he explained. It is especially useful if the GD&T are embedded in the CAD model, such as with CATIA’s Functional Tolerance and Annotation (FTA) or UGX PMI options. He also acknowledges that 90% of his clients still import CAD and read GD&T off an accompanying paper print. “In that arena, again, with our software we try to make it as streamlined as possible for the customer,” he said. If there is a callout a user wishes to comply with, then erroneous attempts to create a measurement out of order or before establishing datums will cause Metrolog to flag an error.

Another approach is to import point clouds and match them to GD&T callouts. That is the approach for SmartProfile from Kotem, a QVI company (Budaörs, Hungary). SmartProfile imports point clouds from part measurements, merges that data with the nominal CAD model of the part with GD&T tolerances, and automatically performs results evaluation. CAD exchange formats supported include IGES, STEP, .stl, or VDA, as well as proprietary formats such as CATIA V4 and V5, Pro/E and UGX.

A crucial step is for users to attach GD&T reference frames to features using the software. This assumes the GD&T is provided separately, still a common practice in most CAD programs. SmartProfile helps users ensure that this tolerancing meets the standards for ASME Y14.5 or ISO 1101. An interactive menu allows users to create feature reference frames with symbols, material conditions, datum reference frames, and numerical tolerances, with explanatory tutorial material if needed. “The editor will provide suggestions and warnings if the entries are suspect or incorrect” as compared to the GD&T standard, according to Gavrail Tatarliev, Senior Software Engineer for Kotem. Once completed, the software then evaluates the point cloud and provides reports on a pass/fail basis. Reports are graphical, text or statistical.

Again, the beauty of using point clouds as the input is that they can be measured on practically any metrology device. For parts with free-form shapes, such as surgical...
implants this is especially useful if a standard GD&T is desired or required. “For example, medical devices often specify only the profile characteristic from the GD&T standard,” explained Nate Rose, Applications Engineering Manager for Optical Gaging Products (OGP; Rochester, NY), another QVI company. “Free form profiles are not easily measured as geometries, but with SmartProfile we can compare the point cloud to the CAD model and evaluate the profile properly,” said Rose.

Future is Automation

Salsbury from Mitutoyo believes the future trend is for programs to automate parts measurements, using pre-determined rules and CAD. “Thousands of lines of code [for parts programs] are generated in a few seconds with a measurement planning...
piece of software, based on certain rules,” he said. If the rules are proper, much of the burden of interpreting GD&T is taken from the end-user.

That is the purpose of Mitutoyo’s newest software MiCAT Planner. It identifies tolerance information included in 3D models with embedded Product and Manufacturing Information (PMI), defines the location for measurement, and creates a measurement program automatically. PMI is also called Model-Based Design, or MBD. The philosophy behind MiCAT according to Salsbury is to aid rather than dictate. “We don’t want to really be the ones setting the rules, but we can help you implement your rules, and we can give you some guidance,” he said, helping balance risk, cost, and conformance.

For example, Capture3D’s software uses MBD by importing CATIA FTA and UGX PMI, as does Metrologic, PC-DMIS, as well as MiCAT and SmartProfile.

While growing, it is a small part of the market today. “Only a small percentage of all of industry today is using MBD,” said Jensen from Hexagon. “We see high end aerospace companies that partner with CAD companies are the ones leading this new technology.”

Want More Information?

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