Validating Tolerances

DEPARTMENTS >> ENSURING EXCELLENCE

Ultra-precise dimensional measurements are critical to risk mitigation under AS9100 Rev. C., easily meeting the gage R&R 10:1 rule.

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Gear Manufacturing Inc. (GMI), Anaheim, CA, was founded in 1989 with a mission to manufacture high-quality custom gears and gear-related components and assemblies. Housed in facilities totaling 27,500ft², the company has 22 of the latest CNC machines capable of gear grinding, gear hobbing, gear shaping, wire EDM, milling, turning, OD & ID grinding, and CMM inspection. Additional support equipment includes 67 manual machines ranging from honing and broaching to thread grinding and baking ovens, all supported by extensive engineering capabilities and leading-edge software.

These photos show an example of a part that Gary Smith says the staff at GMI could not have attempted to machine without an advanced, ultra-precise CMM. The part is a spline rotor, which is key to the operation of a critical-function material feed system. The customer only provided a solid model (STEP file) and nominal dimensions. No conventional manufacturing drawings were available. Driven from the STEP files, Mitutoyo's CAD/CAM systems drove the part through CNC operations to completion.

The company makes almost every type of precision gear and gear assembly configuration imaginable; producing these materials ranging from aluminum and titanium to cast iron, copper, all types of exotic aircraft alloys, and engineered plastics – virtually any material that is used to cut a gear or fabricate gear housings.

Approximately two-thirds of GMI's output is for the aerospace and defense industries. In these markets, GMI's services support Northrop Grumman, Lockheed Martin, Boeing, Bell Helicopter, and Sikorsky Aircraft, to name some of the majors. It will come as no surprise that GMI products comply with standards promulgated by the American Gear Manufacturer's Association (AGMA), Deutsches Institute Fur Normung (DIN), National Aerospace Society (NAS), the Society of Automotive Engineers (SAE), and the American Society of Mechanical Engineers (ASME). In addition, GMI's processes are certified and registered with AS9100 – the aerospace version of the ISO9000 quality management system – recognized internationally by both the SAE and the European Association of Aerospace Industries. Specifically, GMI is certified and registered with Rev. C of AS9100 released in January 2009, and which adds an emphasis on risk mitigation. (*See Sidebar below*.)

Not unexpectedly, GMI's adoption of AS9100 Rev. C has had a major impact on the company's approach to manufacturing management.

Risk Management, Mitigation

Risk management and mitigation is the identification, assessment, and prioritization of risks. As defined by AS9100 Rev. C, risk is the effect of uncertainty, whether positive or negative on achievement of objectives. Risks causing uncertainty can derive from project failures (at any phase in design, development, production, or sustaining life cycles), legal liabilities, financial markets and credit risk, as well as accidents and natural causes. Strategies to mitigate risk typically include reducing the probability of the risk, reducing the negative

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effect should the risk occur, transferring the risk to another party, avoiding the risk, or even accepting some or all of the potential or actual consequences of a particular risk.

The notion of risk is subtle. Gary Smith, president, GMI, comments, “Risk mitigation includes things like having a catastrophe plan in place to account for events including having a key staffer walk out the door to get hit by a truck. Risk can be inherent in PO quality clauses containing some grey areas that may not be fully understood; it might also reside in tight tolerances or other specifications that could be difficult to validate.”

In manufacturing process terms, one aspect of mitigating risk is to be certain that correct revisions of engineering documents, instructions, and specifications are used. When employing tooling and other equipment (including CNC machines), it is essential to demonstrate the integrity of the equipment as related to the suitability and fitness-to-purpose of the items produced. Manufacturing a product as complex as an aircraft or space vehicle requires close attention at every step of the process for every part produced – no matter how very small.

For the staff at GMI, an important area of risk management and abatement is to be sure that the parts they manufacture meet specified dimensional tolerances.

Mitutoyo Legex 574 CNC CMM as installed in the metrology laboratory at Gear Manufacturing Inc.

Gage R&R, the 10:1 Rule

GMI routinely manufactures to tolerances as low as 0.0001". Validating these tolerances can be problematic, especially given the limitations, in terms of gage R&R (repeatability and reproducibility), of both metrology instruments and of their human operators. Gage R&R is the amount of measurement variation introduced by a system comprising the measuring instrument together with the individual using the instrument. Repeatability refers to variation introduced by the instrument; reproducibility refers to variation introduced by the instrument operator. Gage R&R references the combined effect of the two.

Magnifying GMI’s measurement challenge is the fact that its aerospace customers frequently specify that measuring techniques must meet the Gage R&R 10:1 rule. The 10:1 rule holds that total gage R&R should not exceed one tenth that of the tolerance required. For example, if the tolerance is 0.002", then the total of gage R&R should be 0.0002" or better. In other words, the combination of measurement uncertainties introduced by both instrument and human error cannot total more than 10% of the tolerance requiring measurement.

Management found that achieving these levels of repeatability and reproducibility was challenging for even skilled operators using the most accurate hand-held measuring instruments.

“About 20% of the parts we were making were extremely difficult to validate at the tolerances required. Our measurement process involved using high-accuracy super-micrometers and going directly from reference gage block to workpieces – then going back-and-forth from blocks to workpieces. This process burned up a lot of time and motion. Measurements were becoming too time-consuming. A way had to be found to avoid overwhelming our capacity for taking these measurements,” Smith says.

Since GMI’s founding, there has always been the use of Mitutoyo metrology equipment in the facility. As a result of this longstanding relationship, Smith decided to consult with Mitutoyo America to see if they could suggest a solution.

Measuring with Ultra-High Precision

Smith elaborates, “We supplied Mitutoyo with some sample parts and asked for a recommendation. We were looking at tolerances that could go down to as little as 50 millionths on length with measurements that had to comply with the gage R&R 10:1 rule. Within weeks, Mitutoyo came back with an approach based on use of a Mitutoyo Legex 574 CNC Coordinate Measuring Machine (CMM).”

The Legex 574 CMM combines state-of-the-art design, electronics, computing, sensors, and materials to offer substantially enhanced performance while, at the same time, providing a relative price advantage. A total accuracy of 18 millionths (0.000018, MPEE = [0.35+L/1000] µm), a large measuring range of 510mm x 710mm x 455mm, (X,Y, and Z) high traverse speed (200mm/sec), and robust worktable loading capacity (200kgf) make the Legex 574 CNC CMM both productive and practical in diverse applications.

“Furthermore,” Smith continues, “the Accuracy of the Legex ranges from two to 22 millionths at its longest point of travel. The Legex is a lab-grade machine that provides us with part-checking capabilities that can go beyond those of our customers. It has gear geometry checking capabilities and we can use it to calibrate our own gage artifacts. Procuring the Legex was a no-brainer – even had it cost twice what it actually did.”

AS9100 Historical Background

Prior to the adoption of an aerospace specific quality standard, various corporations typically used ISO 9000 and their own complementary quality documentation/requirements, such as Boeing D1-9000 or the automotive Q standard. This created a patchwork of competing requirements that were difficult to enforce and/or with which to comply. The major American aerospace

CMM Operating System

The Legex 574 CMM uses Mitutoyo's the Mitutoyo Controlled Open System for Modular Operation Support (MCOSMOS) operating system. By combining intuitive icon-based programming with the ability to import native CAD models, MCOSMOS enables even novice users to import part and fixture models easily and virtually place them in the volume of their specific CMM. MCOSMOS graphically defines the CMM, racks, probes, and even styli. Selected graphically, all measurement points clearly display on a 3D graphic view that rotates, zooms, or pans to any convenient viewpoint. Animation enables off-line running of a workpiece before ever placing it on the CMM, therefore, providing machine volume verification and collision avoidance. MCOSMOS then enables users to choose various software modules to analyze measurement results, document and present results, and archive the data in practical structures. Furthermore, MCOSMOS integrates with networked systems for in-line process control applications as well as to enable true enterprise-wide functionality.

By incorporating high-level software, CMMs can measure virtually any type of geometry. For example, MCOSMOS includes standard and optional modules, enabling CMMs to:

- Support a variety of probes including contact, constant contact scanning, laser scanning, optical, etc.
- Enable a rotary table to act as a fourth axis
- Create and process prismatic features imported from a CAD model for comparison to nominal values (including animated path generation and collision avoidance)
- Collect data in real-time and net work for SPC
- Evaluate airfoils and turbine blades
- Measure all types of spur (straight or helical), simple and complex segmented gear, bevel (straight or spiral), hypoid, and worm gear profiles and subsequently compare results to international and user- defined standards

manufacturers combined their efforts to create a single, unified quality standard, resulting in AS9000. Upon the release of AS9000, many aerospace manufactures discontinued use of their previous quality supplements in preference to compliance to AS9000.

Working closely with the ISO organization during the ISO 9000 rewrite process for the year 2000 release were members of the AS group. As the year 2000 revision of ISO 9000 incorporated major organizational and philosophical changes, AS9000 underwent a rewrite as well. Release of this rewrite, known as AS9100 to the international aerospace industry, was at the same time as the new version of ISO 9000.

Release of AS9100 Revision C was in January 2009

The gear measurement capabilities mentioned last in the preceding list is possible via the use of GEARPAK – the MCOSMOS software suite enabling GMI employees to measure all the types of gear tooth geometries as described above. Use of it is for rapid generation of measurement program and creates evaluations and reports. Determination of the parameters included in a report comes from the user, with numeric or graphic representations, or a combination of the two.

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Mitutoyo America Corp.'s YouTube Channel offers a range of videos highlighting the metrology products available. View it today at bit.ly/SqXUaU.