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Implementing ISO 18653, *Gears – Evaluation of Instruments for the Measurement of Individual Gears*

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

A trial test of the calibration procedures outlined in ISO 18653, *Gears - Evaluation of Instruments for the Measurement of Individual Gears* show that the results are reasonable, but a minor change to the uncertainty formula is recommended. Gear measuring machine calibration methods are reviewed. The benefits from using 'workpiece like' artifacts are discussed and a procedure for implementing the standard in the workplace is presented. Problems with applying the standard to large gear measuring machines are considered and some recommendations offered.

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Introduction

Cylindrical involute gears are precision components with a relatively complex geometry which must be made accurately to fulfil their specification in terms of noise, power density and reliability. It is common for gears to specify profile, helix and pitch tolerances in the 5–10 μm region and many applications demand tighter tolerances. Modern machine tools, operated in a carefully controlled environment and correctly managed, can achieve these tolerances provided there is an appropriate independent method of measuring the geometrical accuracy of the gears and thus control the process.

The traditional “Golden Rule” for metrology is that the uncertainty of a measurement process should be 10% of the tolerance inspected. Measurement uncertainty is the term used to quantify the unknown random and systematic errors that occur in any measurement process. With tolerances of 5–10 μm , our measurement uncertainty should be 0.5–1.0 μm , on the shop floor, which is still too difficult to achieve and even National Measurement Institutes (NMIs) around the world can only just achieve these levels. Thus the shop floor measuring instrument capability is an important consideration when interpreting measurement result conformance with specification.

In recent years the of range gear measuring equipment available to the gear manufacturer has expanded. There is greater choice of dedicated 4-axis CNC gear measuring machines (GMMs), with three linear axes, a rotary table and tailstock. General purpose co-ordinate measuring machines (CMMs) are now equipped with gear measurement software and previously where only the highest quality machines were considered for gear measurement applications, recent improvements in error mapping to improve measurement performance and the introduction of scanning probes systems has meant that even relatively modest costing CMMs can now be considered for gear measurement applications. The gear

manufacturer has a wider choice of measurement solutions than ever before, but how should the appropriate solution be selected?



Figure 1. CMM used for gear measurement



Figure 2. Example GMM - the UK primary gear measuring machine

It is surprising therefore, that when ISO published ISO 18653 in 2003, *Gears - Evaluation of instruments for the measurement of individual gears* and

a supporting technical report (guidance document) ISO/TR 10064-5 that the gear industry has not adopted the recommendations and applied the standard more widely.

The proposal to develop the ISO document came from AGMA using ANSI/AGMA 2010-A94, *Measuring Instrument Calibration, Part 1 - Involute Measurement* as the working document. Other documents are also used extensively throughout the gear industry. The VDI/VDE guidelines 2612 and 2613 [1, 2] propose limits on measurement uncertainty depending on the DIN 3962 quality grade. They were first published in the 1980s but were revised in 2000. The guidelines also prescribe limits on runout of centers, machine alignment and instrument repeatability and importantly the uncertainty of the calibration data artifacts used to prove machine capability. The VDI/VDE measurement uncertainty limits are used to define the measurement capability of the instruments worldwide.

In the UK in the early 1990s there was general acceptance of the philosophy of the VDI/VDE guidelines but it was considered that more guidance on the procedure to assess measurement uncertainty was required. Also more guidance on the routine testing of measurement instruments was required. The result of this was a series of codes of practice prepared by the UK National Gear Metrology Laboratory (NGML) and published by the British Gear Association (BGA) [3].

One of the reasons that the guidance in ISO 18653 is not more widely adopted is that measurement uncertainty is seldom considered unless a dispute occurs, usually between customer and supplier. The suppliers measuring machine shows the gears are within tolerance and customer's machine indicates the gears are outside tolerance and thus rejects them. Sometimes the cause of the disagreement is simply the interpretation of the specification, a gear mounting error or a mistake in the measurement process but at other times the cause of the differences are more subtle. All measurement processes contain error, including NMI and shop floor machines. The only certainty is that the measurement result is wrong.

ISO 18653 addresses traceability, calibration intervals, sources of measurement uncertainty or

errors, basic instrument checks, environmental conditions, calibration artifact design and provides a method for estimating measurement uncertainty. It contains sound guidance on how to estimate gear measurement uncertainty using simple robust methods. It allows users to assess the differences in measurement instrument capability and thus make informed choices. It minimises the risk associated with high accuracy gearing operating in safety critical situations and allow manufactures to focus on manufacturing gears rather than measuring them.

Calibration methods - micrometer example

It is the experience of the authors that many gear manufacturers consider that they carefully maintain and calibrate their gear measuring machines. Compared to the care taken to calibrate a simple instrument such as a micrometer shown is Figure 3, we do very few tests.



Figure 3. Micrometer and M8 gauge block set used for functional micrometer calibration

A typical micrometer calibration procedure is as follows:

- Check the micrometer spindle is free through its range of operation and the lock functions correctly.
- Verify the fixed anvil is flat within defined limits and free from damage with a calibrated optical flat.
- Verify the moving anvil is free from damage with an optical flat and then verify that the two anvils are parallel within limits with an optical parallel. It

is usual to use 5 optical parallels with different thicknesses arranged to set the spindle at different angles to verify for spindle runout.

- Check the zero point is within acceptable limits and adjust if necessary.
- Use a range of traceably calibrated gauge blocks to verify the measurement performance through the 25 mm range of operation. It is usual to use 8 gauge blocks (M8) set as a functional verification of the performance of the micrometer.
- If all the results are within acceptable limits, the calibration is complete and the micrometer is returned to the shop for use.

In addition, before use every competent operator checks the zero point setting before use and make sure that it is within its calibration interval. We apply these thorough checks to a simple single axis measuring instrument used to inspect simple lengths with tolerances of 15–100 μm .

Many users of gear measuring instruments do not calibrate them with this rigor. Most rely on the machine service engineer to perform a calibration with the gear artifacts supplied with the machine when it was originally installed. They may use a gear artifact to verify the machine at 3 or 6 month intervals and then use a mandrel to check alignment, but in general the measurement uncertainty is only considered when there is problem, flagged by manufacturing machine operators or the customer.

How ISO 18653 works

The key concepts in the ISO 18653 standard are summarized below:

- Measurement uncertainty is assessed by performing a series of measurements on a gear or gear artifact that has been calibrated in an accredited calibration laboratory.
- It is a comparison process: the results from the calibration laboratory are compared with the results from a series of measurements on the subject measuring machine.
- All parameters that the machine will measure and evaluate (profile, helix, pitch and tooth thickness parameters) are analysed.

- The gear or gear artifact should be of similar geometry to product gears inspected by the measuring machine (geometrical similarity implies the same size and weight, module helix angle, facewidth and where possible, the same measurement position and locating arrangement on the measuring machine). Artifact design is discussed in detail in ISO/TR 10064–5.
- It is preferable that data for the series of measurements is gathered over a long period of time so that affects from temperature variation, machine alignment and different operators are taken into account (reproducibility data). The ISO procedure uses the mean and standard deviation from these tests to estimate measurement uncertainty. The minimum number of tests is 10, but 30 is recommended.
- Guidance on other factors that are known to effect measurement results is given such as temperature and instrument alignment (ISO/TR 10064–5 covers these in detail).
- It recommends minimum re-calibration intervals for gear artifacts.
- The methods are consistent with those used for task specific calibration in general metrology with CMMs.
- If the calibration artifact is significantly different to the product gear geometry, additional time consuming tests are needed to establish an uncertainty budget for the product gear. This is why the standard recommends that the calibrated gear is similar to the product gears.
- The subject of fitness for purpose of the instrument is complex and is not covered in the standard but is discussed in detail in ISO/TR 10064–5.
- An accredited calibration laboratory is one that complies with the requirements of ISO 17025, that is laboratories accredited by A2LA, DKD, UKAS etc. The calibration certificate that states how the gear was measured, calibration data and its measurement uncertainty.

Care has been taken when preparing the document to make it applicable to dedicated GMMs and CMMs.

Traceability

The requirement that calibration data is supplied by an ISO 17025 accredited laboratory implies mea-