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Calibration of a 400 mm helical master gear at INRIM

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Abstract

Gears are extremely important mechanical components in very many manufactured products, and crucial in powertrain applications: whenever mechanical power is to be transmitted and/or transformed in angular speed and/or rotation axis, gears enter the game. Just as any other mechanical component, gears range the full scale of size and requirements. Of interest here are the ones with the topmost quality, i.e. bearing the strictest tolerances. In particular, gear masters are intended to provide measurement traceability to gears, and are then required the highest accuracy.

In spite of the very large economic impact of gears, only seven NMI's world-wide (three in Euramet) have CMC's registered in the KCDB in this calibration field, and not all covering all areas. In particular, only four (one in Euramet) have got CMC's for lead masters.

The European project Drivetrain (EMRP ENG56, ending on August 2017) is about large drivetrain components particularly for wind energy systems. Among its objectives, it aims at improving the gear calibration infrastructure, providing committed project partners – including the INRIM – with the opportunity of investigating and exercise. A project deliverable was the calibration of a 400 mm helical master gear. The measurands were the profiles and the leads of four selected teeth angularly spaced 90° about the gear axis, and the pitch and runout.

The calibration occurred at the INRIM in December 2016 and January 2017 and was done with a CMM (Leitz PMM-C 12107) not equipped with a rotary table. Because of that, the stylus system was set up with four horizontal equally spaced styli. A fifth vertical stylus was added for alignment of the master – thus completing the conventional star set up (see figure).

The calibration was carried out in two steps, following common practice at INRIM for calibrations by means of coordinate metrology.

1. The first step was intended to introduce traceability. Three mutually orthogonal elementary features of the master, each aligned to a CMM axis, were calibrated. As these calibrations were done prior to the rest, they were referred to as *pre-calibrations*. The features were two point-to-point internal diameters of the upper flange (along x and y) and the axial separation of the upper and lower faces (along z). Because the shaft seat prevented a direct axial measurement and for sake of symmetry, the face separation was defined more precisely as the mean separation of two corresponding point pairs on the upper and lower flanges, symmetrically to the gear axis. Each feature was calibrated by comparison with an aligned calibrated gauge block of similar length.
2. The second step performed the full measurement of the master, as well as a repetition of the measurement of the three pre-calibrated features. The x coordinates of all measured points were stretched (i.e. multiplied by a common factors close to unity) to make the repeated measurement value of the pre-calibrated x feature match the pre-calibrated value. The same was done separately for y and z.

This way, the traceability brought in by the pre-calibrated features was extended to all other features. The first step only suffered uncertainty due to thermal expansion, as the stretches occurring in the second automatically recovered any expansion (no thermal compensation done in the second step).

The evaluation of the uncertainty was particularly challenging (more details in the presentation):

- The input uncertainties were evaluated based on experimental data or expert judgment. The important effect of the scanning probing was evaluated experimentally by scanning a reference sphere: paths were selected accurately to have normal directions to the material mimicking those of the actual tooth measurement, separately for profile and lead scans.
- The geometric complexity of the teeth prevented a rigorous analytic derivation of the sensitivity coefficients as partial derivatives. Simplified intuitive models were considered but not used, as this calibration was the first ever in the laboratory and no previous experience was available to validate any simplification. The sensitivity coefficients most difficult to predict were derived by adapting the suggestion given in [1] § 5.1.3 Note 2. The measured points were collectively perturbed in software to simulate each individual error of a known amount (e.g. a 50 µrad rotation about the axis x to simulate the effect of a poor establishment of the coordinate system), the gear re-evaluated, and the sensitivity coefficients derived as incremental ratios.

The exercise was not a formal comparison. Nevertheless, the results were compared with reference calibration values provided by the NGML (GB). The comparison was satisfactory, with all normalized errors less than unity but one isolated case slightly in excess. The uncertainty achieved was in line with other NMIs' holding gear CMC's. This poses the basis for submitting a new CMC.

Not using a rotary table for the calibration cleared from a number of table-related uncertainty components. On the other hand, the scanning probing system was exercised over a range of spatial directions, instead of essentially a single direction as in the case of the rotary table. It was no surprise that the uncertainty budget resulted dominated by the scanning probing system.

[1] JCGM 100:2008 Evaluation of measurement data — Guide to the expression of uncertainty in measurement