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TRACEABILITY STRATEGIES FOR THE CALIBRATION OF GEAR AND SPLINE ARTEFACTS

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Abstract: In accordance with ISO 17025, measuring and test equipment, including gear and spline artefacts must have been traced back to recognized national or international primary standards through an unbroken traceability chain. This is the reason why there have been national gear standards and gear standard measuring equipment in Germany since the sixties, for example for the elements: profile, helix, pitch, radial run-out of gearings and roughness. In contrast to this, no direct link-up to spline artefacts has so far been made at the PTB for splines. If one proceeded in compliance with the DKD traceability criteria applicable to other geometrical measurands within the DKD, a large number of PTB calibrations against the PTB's reference standards or comparison measurements of spline gauges with the PTB would have to be performed, of course at relatively high cost. In this lecture, the most recent traceability strategies for different levels will be discussed.

By bringing up this topic, the author aims to point out that one should start thinking about the necessity of defining traceability criteria within the meaning of ISO 17025, which are uniform all over the world so that mutual recognition of the measurement results for gears and splines can be achieved on the international level.

Keywords: calibration, traceability, gears, splines

1 INTRODUCTION

It is the purpose of this lecture to launch a critical examination of the common measuring strategies used and of the uncertainties of measurement achieved for complex machine elements such as gears and splines, and this with a view to improving the comparability of measurement results on the international level. It is not sufficient to demand, in compliance with ISO 17025, that all simple measuring and test equipment should have been traced back to national standards unless the complex measuring methods for important machine elements are discussed on the international level and appropriate directives drawn up.

2 GENERAL TRACEABILITY STRATEGIES (METHODS)

Gears and splines can up to now be measured on single-purpose measuring instruments, using manual measuring instruments or coordinate measuring machines (CMM). Accordingly, there is a choice of different traceability strategies. In a modified form, the strategies (methods) referred to below are, however, applicable to all kinds of measuring instruments (mechanical and CNC-controlled).

2.1 Method A

Method which was already generally applicable 30 years ago and is widely used still today:

(a) The measuring instrument is adjusted in accordance with the manufacturer's specifications.
(b) The measuring instrument is calibrated neither with respect to the device nor with respect to the task.
(c) Measurement results have not been traced back and thus are not very reliable.
(d) On balance the uncertainty of measurement U is very great.

2.2 Method B

Method which is sufficient for a great number of measuring tasks and can be regarded as furnishing appropriate traceability according to EN 45000/ISO 17025 if the uncertainty of measurement is great enough. This is also referred to as global accreditation.

(a) The measuring instrument is traced back only with respect to the device (for example, with gauge blocks, step gauges, lasers, rules, ball or hole plates).
(b) The task-specific uncertainty of measurement is estimated by computation or by internal intercomparisons.
(c) Measurement results have been traced back but not reliably enough (for example, because when the instrument is calibrated, tracing takes place in the direction of the normal, whereas it is, for example, made at an angle when a workpiece is measured).
(d) Result: On balance the uncertainty of measurement U can be taken as smaller than for method A but it cannot be stated reliably enough for workpieces with a complicated geometry.

2.3 Method C

Method which has been used at the PTB for artefact calibration for industry for 30 years.
(a) The measuring instrument is traced back with respect to the device (see B).
(b) The task-specific tracing is carried out with traced-back artefacts which are similar to the workpieces to be measured later.
(c) The measurement results have been traced back and are also reliable as regards the measurement of workpieces with a complicated geometry.
(d) Result: On balance the uncertainty of measurement can be reliably stated and is relatively small. Restriction: It is fully valid only for certain ranges of measurement and only for workpieces for which artefacts are available. The calculation of U is mainly based on the measurement results (comparison between workpiece and standard).

2.4 Method D

Method which is used relatively rarely.
(a) The instrument is traced back with respect both to the device and to the task only in a partial range of measurement with the aim to reduce the uncertainty of measurement of the instrument. Partial range of measurement can also mean that the instrument is traced back only in one coordinate and is later on used for measurement though there are two or three coordinates.
(b) See method C.
(c) See method C.
(d) Result: The uncertainty of measurement can be smaller than for method C but the measuring instrument is not fully utilized as regards range of measurement and measurement capabilities.

2.5 Method E

Method which has its origins at the PTB and is still under development on the international level. It most certainly will mark a progress. It is for the time being investigated only for CMMs.
(a) The measuring instrument is traced back with respect to the device in a modified form; the recalibration and supervision intervals are to be carefully fixed.
(b) The task-specific uncertainty of measurement is estimated objectively by the method of the so-called virtual CMM. The behaviour of the measuring instrument is determined by simulation of task-specific measurements (i.e. workpieces of different geometry). What is obtained is the task-specific uncertainty of measurement, always without using artefacts.
(c) The measurement results have been traced back, also with respect to the task, by meeting certain prerequisites (correct algorithms, environmental conditions, long-time stability of the instrument, etc.).
(d) Result: On balance the uncertainty of measurement U can largely be reliably stated. The number of artefacts can at least be strongly reduced.

2.6 Method F

Method which is very reliable but for reasons of cost is certainly suitable only for primary laboratories, i.e. mainly for NMIs and laboratories which are authorized to ensure traceability to national standards.
(a) The measuring instrument is traced back with respect both to the device and to the task (by very accurate artefacts and simulation). If it is not an NMI which is concerned, the laboratory must have been accredited, for example, by the DKD, UKAS, AFNOR, etc. This means that also the staff, the ambient conditions, the calibration intervals, etc. are supervised.

(b) The calculation of the overall uncertainty of measurement (according to GUM) for all artefacts (measurement standards, master pieces, etc.) is based on optimum device- and task-specific (artefacts plus virtual CMM) traceability.
(c) The measurement results are very reliable and must also be recognized in accordance with ISO 17025.
(d) Result: On balance this method involves great expenditure which is, however, justified if very small uncertainties of measurement must be achieved.

2.7 Method G

Method which is still common practice in gearing metrology in particular.
(a) The measuring instrument is traced back and calibrated (for single-purpose measuring instruments in particular) only with respect to the task. The task-specific standards (master gears, gear standards) are calibrated directly by an NMI (for example, the PTB) and then used for internal calibration of one's own devices or at the customer's. The recalibration intervals are not ever specified.
(b) The task-specific uncertainty of measurement is well known and reliable, while the reliability of the device-specific uncertainty is smaller.
(c) The measurement results have been traced back, particularly when the substitution method is used (workpiece and standard are similar as regards dimensions and form).
(d) Result: On balance this method is cost-advantageous but the instrument can be used only for specific purposes.

2.8 Method H

Strategy which is applied when no standards exist and not much experience is available but small uncertainties of measurement are required nevertheless (for example, in the nanometer range for mask standards but also for gear standards).
(a) The measuring instrument is traced back by including it in international or national comparison measurements on transfer standards. The mean value then is the reference value without the magnitude of the systematic errors (deviations) being exactly known.
(b) The uncertainty of the comparison measurements is obtained from the comparison of the individual values of every country with the mean value, considering the respective different uncertainties of measurement.
(c) The measurement results have been "virtually" traced back without direct verification.
(d) Result: On balance the method is well suited for achieving comparability on the international level for the benefit of the international market (globalization). Expensive standard measuring facilities are not required. At present, so-called key comparisons are organized all over the world, i.e. many countries achieve traceability for certain measurands on the basis of the results of comparison measurements.

3 TRACEABILITY STRATEGIES FOR GEARS

In section 2, calibration methods have been described, which are generally applicable to geometrical measurands. Section 3 will demonstrate a calibration chain for gears as realized in Germany by an example. In the lecture one Figure shows the calibration chain for the involute which begins with the realization of the SI unit meter as defined, with which selected wavelength standards are linked up. Comparators whose material measures are in turn compared with these wavelength standards serve to determine the geometrical measurands (for example, diameter, roundness, distance) required for the realization of the national involute standards. On a standard measuring device developed at the PTB for the calibration of these involute standards, the actual values of position, dimension and form of the involute are determined (Figure 1).

The calibration of involute reference standards is then carried out on calibrated CMMs, including these national involute standards (substitution method) to further reduce the uncertainty of measurement. Of course the traceability of the CMMs – also beginning with the SI unit meter – has been realized. In accordance with section 2, method F has been used here to achieve minimum possible uncertainties of measurement with highest reliability. For the sake of completeness: The reference standards calibrated by the PTB are used in industry to calibrate and supervise the instruments for gear measurements.

It is to be pointed out that the PTB has been declared by EUROMET to be a European Reference Laboratory. In an International Gear Metrology Round Robin published in 1999 by Frazer (UK), the results of the PTB are therefore used as reference values. Participants were the USA, Japan, China, France, the UK. The results were in relatively good agreement, but the workpieces were cylindrical gears with favourable dimensions. The comparison remains to be recognized as a so-called key comparison.

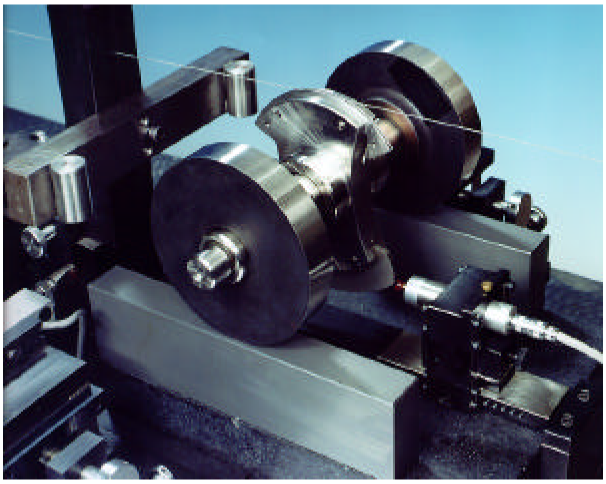

Figure 1. Involute standard deviceof PTB.

4 TRACEABILITY STRATEGIES FOR SPLINES

Splines are used for torque transmission (in the same axis). They are needed when (a) the driven component must be shifted on the driving component (in the case of change speed gears and clutches) and (b) when two components for torque transmission must be separated for reasons of manufacture (for example, in the case of steering mechanisms).

Splines are to be centred as well as possible. They are to have little backlash, low noise and a low rate of wear. From this it follows that the geometrical tolerances, too, must be relatively small, similar to those of gearings (depending on the accuracy class).

In spite of almost equal accuracy requirements, the situation worldwide is substantially worse than for gears. It will be shown by the example of tooth thickness that, at present, only method B resp. method C (with limitations) according to section 2 is applicable; Figure 2 shows the calibration chain realized for tooth thickness at the PTB.

Figure 3. Tooth thickness standard of PTB.

But up to now, the PTB did not have primary standards for tooth thickness (for splines). In 1999, it was attempted for the first time to estimate realistic uncertainties by measurement of a tooth thickness standard (Figure 3) with different methods on two CMMs.

All measurements were calibrations more ore less by method B resp. C according to section 2 (i.e. completely traced-back CMM plus comparison with an exact, equal spline standard which has not, however, been directly traced back). It was the aim of these investigations to demonstrate that at present the usual manual measuring instruments and the coordinate measuring machines which are not traced back do not allow the required small uncertainties of measurement to be achieved. On the other hand, it should be proved that it is possible only with very great metrological efforts to reach a task-specific uncertainty of measurement of 1...2 µm. The PTB carried out the measurements with the separately fabricated tooth thickness standard on two different CMMs by four different measuring strategies. Basically, the one-ball method was used, i.e. the measurements were related to the very good cylindrical reference surfaces.

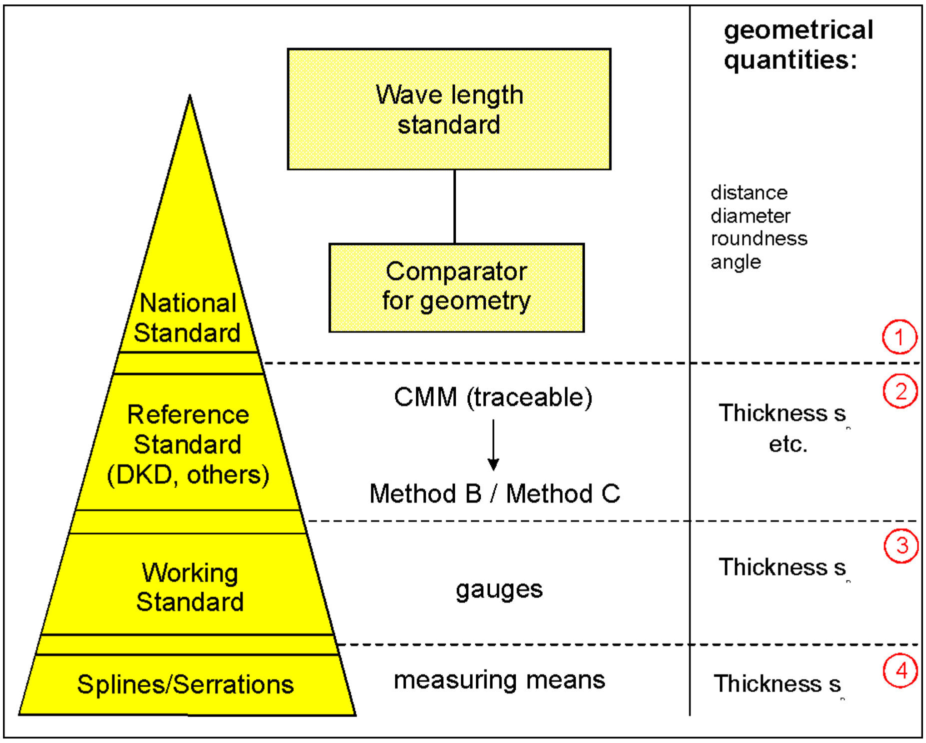

Figure 2. Calibration chain of PTB for the measurand "tooth thickness" (for splines).

The mean value of all measurements on this artefact was equated to an artefact which had really been traced back with respect to the task. The PTB will try to define also the traceability criteria for other measurands of the splines (for example, for major/minor diameter, circumferential backlash, etc.) in dependence on the uncertainties of measurement desired. These traceability criteria must, however, be harmonized and accepted on the international level for the comparability of measurement results and thus mutual recognition of certificates to be guaranteed.

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