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Design, manufacturing and calibration of a large ring segment

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Abstract
Design concepts, manufacturing steps and calibration strategies of a large ring segment are reported in this contribution. The study aims at investigating the feasibility of using a ring segment for establishing the traceability of large diameter workpieces, primarily to quantify the influence of the workpiece surface and form.
The ring segment embodies two nominally coaxial features: a cylinder and a torus. Both the cylinder and the torus are highly partial features, which poses a challenge for the calibration. The measurands to calibrate are defined in terms of intrinsic and location features, according to the model for geometrical specification and verification (EN ISO 17450-1). The adopted measurement strategies are described and preliminary calibration results are reported.

Keywords: ring segment, large diameter workpieces, form and size measurements, bearings, drivetrain components

1. Introduction

The feasibility and calibration of new measurement artefacts/standards is today an issue to improve/extend traceability in production-related measurements of large size components, e.g., large drivetrain parts used in wind and conventional power generation systems [1].

The study aims at investigating the feasibility of using a ring segment for establishing the traceability of large diameter workpieces, primarily to quantify the influence of the workpiece surface and form, which are generally the largest sources of noise and vibrations of critical rolling surface, e.g., bearings [2]. Measurements of form, sizes and texture of cylindrical- and torus-shape surfaces are needed to qualify raceway conformity and geometries of large bearings cups.

The purpose of this paper is to introduce a novel artefact, leaving its actual exploitation to a later paper.

2. Design

The general design considerations are such to have a new portable ring segment measurement gauge with a torus/circular groove in the axial direction; a segment which is representative of bearing rings with diameter of about 1 m. Besides, the ring segment size (Fig. 1) does not exceed the measurement volumes of form and surface texture measurement systems usually available at metrology labs.

3. Manufacturing

The standard is made of AISI 440C stainless steel, treated and stabilized to achieve a hardness value greater than 60 HRC (up to the core). After milling, it was heat treated, and finished by a coordinates grinding machine for the cylindrical profile and by a form interpolating grinding machine, for the torus profile. Particularly, the torus profile has been gotten outlining the grindstone as a sphere and reproducing its form on the standard by abrasion.

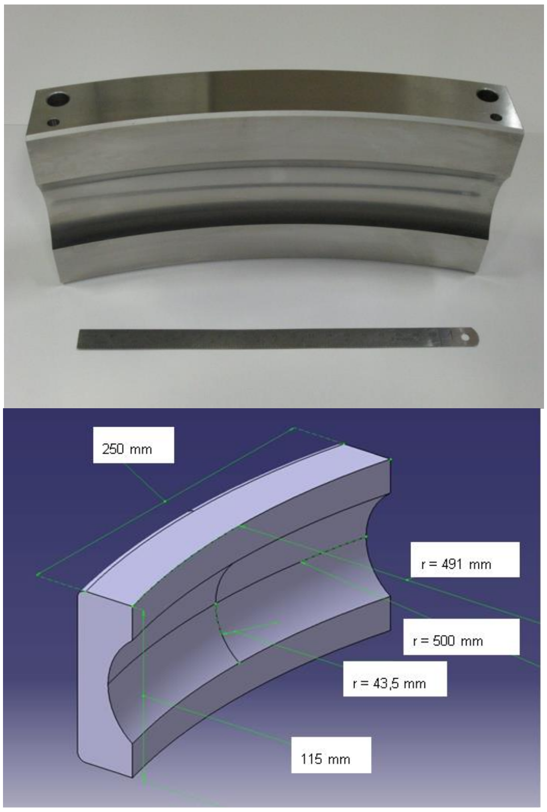

Figure 1. Photograph and rendering with dimensions (nominal values) of the ring segment.

3.1. Processing Steps

1st step: starting from an AISI 440 C parallelepiped and by using a 3 axes vertical machining center (FADAL 3016 L) a pre-rough machining phase was made to obtain the ring segment complete of the torus profile with 2 mm machining allowance.

2nd step: The ring segment was treated as follows:

2a: washing with solvent at 124 °C for 15 min;

2b: stabilization (in a protective atmosphere; gaseous mixture of N_2 (94%) and H_2 (6%)) at 650 °C for 120 min followed by cooling in an oven at 300 °C and then in still air down to room temperature;

2c: hardening with pre-heating to 760 °C for about 40 min, and reheating to 1070 °C for 45 min (always in a protective atmosphere);

2d: cooling in ventilated chamber for 60 min;

2e: double-cycle cooling at -100 °C for 4 hours (at the end of each cycle, the master was brought back at room temperature);

2f: tempering by heating at 145 °C for 5 hours, natural cooling at 80 °C and again heating to 145 °C for further 5 hours and natural cooling at room temperature.

3rd step: using a Cartesian coordinate grinding machine (Hauser S40 DR) the reference holes on the top plane of the segment were grinded. These holes represent reference positions for pins in the following operation of finish grinding. The rough-grinding of the cylindrical profile was performed by the same machine.

4th step: by means of a form interpolating grinding machine (Studer S41), the finishing grinding of the torus and of the cylindrical profile was made. The torus is obtained using a plunge grinding strategy with a sphere grindstone, outlined on the same machine using a single diamond tool. The entire phase is performed under coolant emulsion jet (mixture of water and oil 8%) to avoid thermal stress on the material.

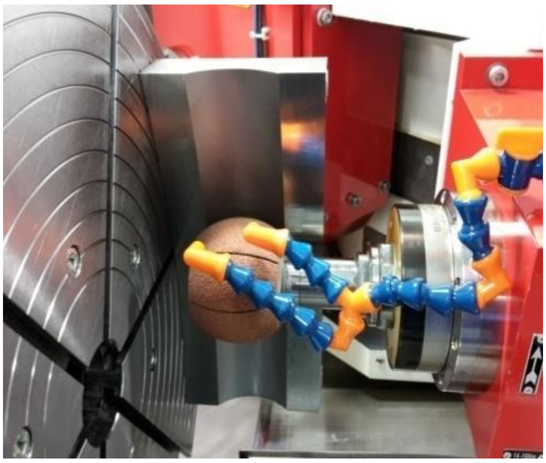

Figure 2. Fine grinding of the torus as made by a pre-formed spherical tool.

4. Measurement /Calibration

The ring segment embodies two nominally coaxial features: a cylinder and a torus. Both the cylinder and the torus are highly partial features, which poses a challenge for the calibration [3]. In particular, the torus is partial along its ring and its tube, and the cylinder has an aperture of roughly 30° for a diameter of about 1 m. The measurands to calibrate are defined in terms of intrinsic and location features, according to the model for geometrical specification and verification (EN ISO 17450-1).

4.1 Measurement strategies

Measurements have been performed by CMMs and form/roughness measurement systems. Traceability of CMM measurements is underpinned by suitable standards. The height of the cap of the cylindrical sector is traced to a gage block of the same length of the ring sector, wrung of a flat reference plate, whereas the circular groove of the torus is traced to a ring standard of the same size. Besides, a straightness standard is used to correct the straightness error of the relevant portion of the CMM axis the ring sector is aligned to.

In a first step, the distance of the two reference pin seats of the standard are calibrated with a CMM by comparison with a calibrated long gauge block. This provides traceability in the tangential direction of the standard. In subsequent measurements, this distance is measured again, and the coordinates along that direction of all measured points are stretched so as to achieve the calibrated value. This also correct for thermal expansion in that direction.

In a second step, individual longitudinal traces of the torus are compared with a calibrated ring standard, to obtain calibrated values of such traces.

In a third step, all remaining measurements are taken, with the addition of a short calibrated gauge block which provide traceability along the radial direction. The resulting proportional correction is then propagated to point coordinated in that direction. A calibrated straight edge is also measured, to correct for the CMM straightness. The fact that the measured features are highly partial amplifies the CMM errors, specifically the scale error in the radial direction and the straightness error along the tangential direction. These are recovered by comparison with the short gauge block and with the straight edge. For the torus, all (systematic) errors are corrected by comparison with the calibrated ring.

Form/roughness systems are calibrated by means of high quality spheres, which in turn are calibrated by roundness and diameter measurements.

Table 1. Preliminary results.

Cylinder	
Radius (DfN)	0,16 mm
Form	9,2 µm
Torus	
Tube radius (DfN)	0,58 mm
Overall radius (DfN)	-0,10 mm
Coaxiality torus - cylinder	
Radial	6,15 µm
Tangential	0,51 mm
Angle torus - cylinder axes	
Radial plane	-69 µrad
Tangential plane	-0,43 mrad

DfN = Deviation from nominal

Measurements are currently in progress. Preliminary results still without the above described compensations are reported in Table 1. Some values of deviation from nominal (DfN) are large due to the extreme partialisation of the involved features, particularly the torus tube. The torus to cylinder location is very different in the radial and tangential directions: the latter has weak components to the surface normals (i.e. the probing directions).

Acknowledgments

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