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Uncertainty of pin height measurement for the determination of wear in pin-on-plate test

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ABSTRACT

The paper concerns measurement of pin height for the determination of wear in a pin-on-plate (POP) or pin-on-disc (POD) test, where a pin is mounted on a holder that can be fixed on the test rig and removed for measurements. The amount of wear is assessed as difference of pin height before and after the test, using the distance between holder plane and pin friction plane as measurand. A series of measurements were performed in connection with POP testing of different friction material pins mounted on an aluminium holder. Pin height measurements were carried out on a coordinate measuring machine (CMM), achieving an expanded measurement uncertainty ($k = 2$) better than 1 μm. A simple dedicated fixture adaptable to workshop environment was developed and its metrological capability investigated, estimating an average uncertainty of measurement in the order of 5 μm ($k = 2$). Fixture measurements were compared with CMM measurements using the normalised E_n value. Acceptable E_n values ($E_n < 1$) were obtained in 58% of the measurements, showing a discrepancy which was explained in terms of different probing patterns on CMM and fixture.

1. Introduction

Wear can be investigated using several tests including pin-on-disc (POD) and pin-on-plate (POP) test rigs [1–3], the POP test being particularly suitable for investigations with low speed and motion inversions. For this test, a friction material pin is typically mounted on a holder, e.g. made out of aluminium. Options for wear measurement include assessing pin weight variations, volume changes from profilometry, or variations measured by distance sensors mounted on the test rig and operated during the POP test [3]. In this work, wear is assessed through dimensional measurements using a coordinate measuring machine (CMM). CMM measurements entail high accuracy, reproducibility, repeatability and flexibility but require trained operators. A simple dedicated fixture adaptable to workshop environment for use in conjunction with an existing POP test rig was developed and its metrological capability investigated. Scope of this work is to document the uncertainty related to the measurements performed with the two methods.

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2. Measuring task

2.1. Specimen and measurand

The specimen, shown in Fig. 1, consists of a cylindrical pin with 10 mm diameter and a height of 8 mm, made of friction material glued in an aluminium holder with a diameter of 29.5 mm and a height of 9 mm, suitable for installation and operation in a POP test-rig [3]. The pin protrudes from the holder by nominally 2 mm, being the part subject to wear during the test. Different friction materials such as organic (denominated by A), fibre-composites (B and C), thermoplastic resins (D and E), and sintered powders (G) were tested in dry and lubricated conditions [3]. Each specimen was electro-marked in two positions: on holder base with an identification code determining univocally material, serial number, and lubrication condition; on holder side with a line for specimen orientation during test as well as during dimensional measurements. Out of a total of 55 specimens measured for project purposes, this work focuses on the results of those nine specimens that underwent fixture measurements and at least six CMM measurement repetitions.

The difference between initial and worn condition of the pin height h, see Fig. 1, enables the wear estimation. The surface represented by plane A was produced by fine turning. The surface represented by plane B was originally produced by fine turning but subsequently altered by wear.

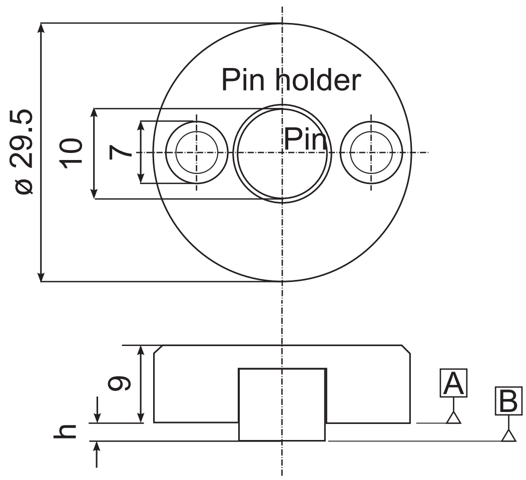

Fig. 1. Definition of measurand as the distance between holder plane A and pin plane B.

The measurand h is here defined as average distance between plane A on the holder and plane B representing the pin friction surface, see Fig. 1. Measurand complete value $h = \bar{h} - b \pm U$ includes the compensation for systematic errors b and the expanded uncertainty measured according to the Guide to the Expression of Uncertainty in Measurement (GUM) [4].

3. CMM measurements

3.1. Equipment

A Zeiss UPMC 850 Carat was utilised for the measurements in a controlled environment laboratory at the department's Center for Geometrical Metrology (CGM). Measurements were carried out in a temperature range of 20.2 ± 0.24 °C. The machine is equipped with a universal 3D probe head for data acquisition with multi-point measurement and scanning. The machine resolution is 0.1 µm. The installed measuring probe has a diameter ∅ 4 mm. The probing force is 0.1 N. A 60° indexing fixture permits clamping of the specimen with repeatable positioning on CMM's table (Fig. 2). Specimens were acclimated over 24 h before measurement.

3.2. CMM calibration and measurement procedure

The CMM was calibrated by the supplier according to ISO 10360 [5], and its maximum permissible error (MPE) $u_1 = (0.4 + L/900)$ µm in one-dimensional length measurement verified. A grade 0 gauge block wrung on an optical flat was measured as traceable reference before and after each measurement series. Reference measurements were performed using the same point positions as for measuring the specimens (Fig. 3).

The pin height h (Fig. 1) was determined on the CMM as the distance between the least square planes (LSP) defined by, respectively, 16 points on the holder surface (plane A) and 9 points on the pin surface (plane B), see Fig. 3. The CMM was programmed to carry out a rough alignment and to position the coordinate system relatively to the specimen while an eventual fine alignment was used to define LSP A on the holder.

3.3. Error compensation and uncertainty budgeting for CMM measurements

Uncertainty budgeting includes (i) reference uncertainty u_{r1}, (ii) uncertainty from calibration u_{r2}, (iii) uncertainty from ambient temperature variations u_e, and (iv) uncertainty from procedure u_p:

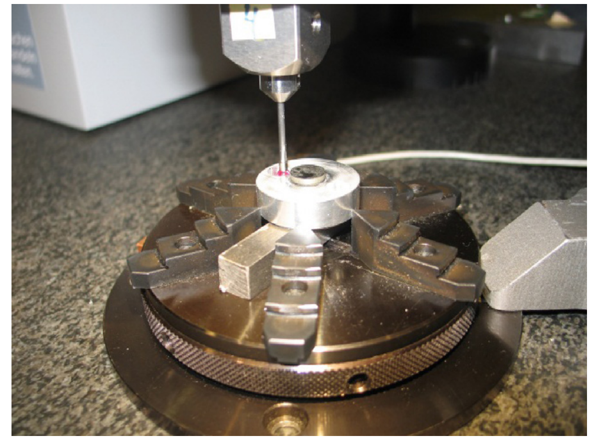

Fig. 2. Specimen on indexing fixture being measured by the 4 mm probe.

$$U = k \times \sqrt{u_{r1}^2 + u_{r2}^2 + u_e^2 + u_p^2}$$

The reference calibration uncertainty u_{r1} is based on a ISO 3650 grade 0 gauge block with limit deviation from nominal length of ± 0.14 µm and using a rectangular distribution; the uncertainty resulting from the calibration procedure is calculated as $u_{r2} = t(s_r/\sqrt{n_r})$, where s_r is the standard deviation of measurements of the distance between optical flat LSP and gauge block LSP, n_r the number of repeated measurements, and t Student's value; the uncertainty due to ambient temperature variations: $u_e = \text{distribution} \times |\Delta t \times \propto_{\text{combined}} \times h|$, where distribution is U-type with coefficient 0.7, and $\propto_{\text{combined}} = (h_{\text{pin}} \times \propto_{\text{pin}} + h_{\text{holder}} \times \propto_{\text{holder}})/(h_{\text{pin}} + h_{\text{holder}})$ is due to the thermal expansion of the pin and the holder. The CMM software corrects the measurements in relation to machine's expansion coefficient. The procedure standard uncertainty was calculated based on individual specimen LSP height $u_p = t \times (s/\sqrt{n})$, where s is the standard deviation of specimen height measurement, n the number of repetitions carried out on the same specimen, and t Student's value. Table 1 outlines the uncertainties

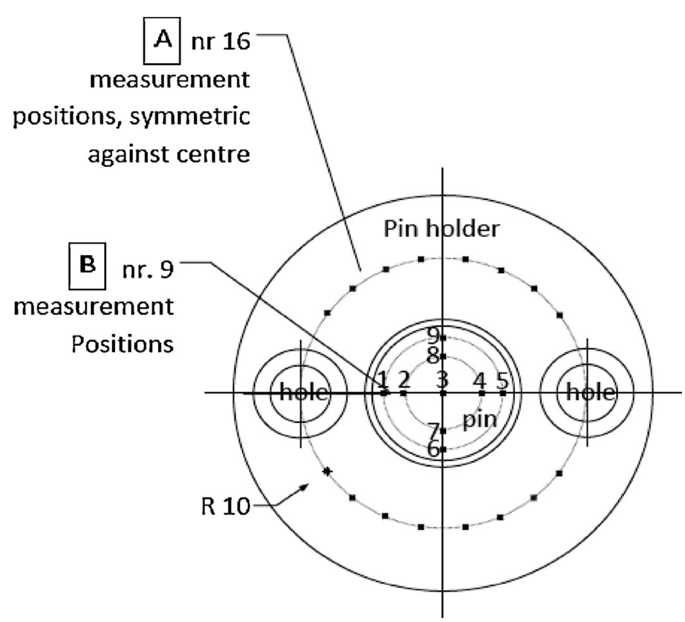

Fig. 3. Position of the 16 points determining least square plane (LSP) A on holder and of the 9 points for determining LSP B on pin, during CMM measurements. Holes in the holder are used for fixing in the POP rig.