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Performance evaluation of a CMM tactile scanning probing system according to the revised ISO 10360 standard

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Abstract

In recent years the procedures described in the ISO 10360 standards on a*cceptance and reverification tests for CMMs* have changed drastically. Although the line of thought has not changed much, testing parameters have been extended and the symbolic annotation has altered significantly. This paper elaborates on the revision of *ISO 10360-4:2000: CMMs used in scanning measuring mode*. This component is going to be incorporated in the updated *ISO/CD 10360-5:2017* on contacting probing systems. The changes embody modifications in symbolic representation, alterations in procedures and equipment description and the addition of two parameters. The new parameters are the scanning mode size error on a sphere and its MPE value, resp. $P_{Size.Sph.Scan:k:Tact}$ and $P_{Size.Sph.Scan:k:Tact,MPE}$. The work presented here exemplifies all theory with a real set of measurements, conducted on a state-of-the-art CMM.

Coordinate Measuring Machine, CMM verification, Tactile scanning probe, ISO 10360

1. Introduction to tactile scanning probing system verification

Industrial development has resulted in further widening of the variety of coordinate measuring systems (CMSs). The appearance of novel and the maturation of existing industrially used techniques led to an increasing need of a revision of the ISO 10360 series: *GPS - Acceptance and reverification tests for coordinate measuring machines (CMM)* [1]. New parts have been recently added (ISO 10360-10:2016 on laser trackers and ISO 10360-12:2016 on articulated arm CMMs) or are under construction (ISO/NP 10360-11 on X-ray CT devices) [1]. Within the standards that deal with tactile probing systems for CMMs [1], testing parameters have been extended and the symbolic annotation of all parameters has altered significantly. As *a major structural change* the fourth part of the series (*ISO 10360-4:2000)* for tactile scanning will be absorbed by part 5 in the revision under construction (*ISO/CD 10360-5:2017)* [1].

Tactile scanning probing systems are regarded as contact probing systems that probe a surface through scanning which is a particular probing mode for taking consecutive measured points on an inspected surface [1]. It is used for curved surfaces where denser data sampling is desirable [2, 3]. It is also used for establishing calibrated reference values for artefact dimensions and form deviations used in less precise techniques such as X-ray CT [4, 5]. The accuracy of tactile scanning still improved through further research [6-8]. Similar work to apply verification procedures through ISO 10360 has been conducted for various probing systems [9-11].

Alterations are proposed in *ISO/CD 10360-5:2017*, such as modifications in symbolic notation and the addition of extra parameters. The new parameters are the scanning mode size error on a sphere and its maximum permissible error (MPE) value, resp. $P_{Size.Sph.Scan:PP:Tact}$ and $P_{Size.Sph.Scan:PP:Tact,MPE}$ [1].

2. Modifications and absorption in ISO/CD 10360-5

Before discussing content modifications, some structural differences are pin-pointed. Most of the content is unchanged, yet the structure of the tactile scanning probing paragraphs has been altered (the *environmental* and the *operating* conditions regrouped as *rated operation conditions*; the stylus system and the measuring equipment specified in a different place). The standard will more clearly stress the importance of both the temperature influence (bounds and desired approximate equilibrium) and the general decision rules (incorporation of measurement uncertainty on the outcome results according to ISO 14523-1). Concerning the test sphere, several details were added. The actual diameter is now also limited to a range of 24.9 - 25.5 mm. The form error, FCal, and the calibration uncertainty, u(FCal), received boundaries (Eq. 1-Eq. 3) [1]. These rules do not make the measuring equipment choice stricter, yet it assures the uncertainty related to its use diminishes and more importantly can be estimated properly.

$$FCal < 20\% \cdot P_{Form.Sph.Scan:k:Tact:MPE} \quad \text{(Eq. 1)}$$

$$FCal + 1.65 \cdot u(FCal) < 25\% \cdot P_{Form.Sph.Scan:PP:Tact:MPE} \quad \text{(Eq. 2)}$$

$$FCal + 1.65 \cdot u(FCal) < 2.5\ \mu m \quad \text{(Eq. 3)}$$

Lastly, there is the removal of the separation between high density and low density scans. The new edition will provide a higher bound for the distance of consecutive corrected measured points, namely 0.1 mm (formerly high density) [1].

As ISO 10360-4:2000 is only applicable to tactile systems, it will in the future be integrated in the general part addressing all kinds of tactile probing systems (ISO/CD 10360-5:2017). This umbrella part will cluster the tactile tests. The first part, the single-stylus probing test, is preferably done before the linear dimension verification of ISO 10360-2:2009; the other sections are dealt with after [12]. Dependent on applicability one or more are selected from the following list: fixed multi-probe and multi-stylus test, articulating probing test or scanning mode test.

3. Tactile scanning mode verification parameters

The verification parameter set is based on the definitions from ISO 10360-1:Vocabulary. As this standard dates back to 2000, it is still employing older terms and definitions and symbols, thus ISO/CD 10360-5:2017 introduces and supersedes many of the definitions, although having the same basis [1]. For tactile scanning probing the number of parameters will increase.

The scanning time aspect remains unchanged. The scanning time, formerly τ and in the future $\tau_{Sph.Scan:k:Tact}$, is to be recorded and has to stay below the maximum permissible value [1].

The current verification parameter set from ISO 10360-4:2000 will however be extended. As it embodies measurement spread through the range determination and the precision is not addressed in a different specific parameter, it leads to difficulty in interpreting MPE values when its criterion for acceptance is not met. The current single parameter approach, with the scanning probe error parameter *Tij* (Eq. 4), is often too limited to conclude where the issue may lie when the verification fails. The use of the second parameter check in ISO 10360-4:2000 (Eq. 5) does often not clarify the source. The new approach from ISO/CD 10360-5:2017 tackles this problem by deduplicating the parameter in a precision-based and a spread-based component resulting in two separate parameters, namely the scanning mode size error $P_{\text{Size.Sph.Scan:PP:Tact}}$ and the scanning mode form error $P_{\text{Form.Sph.Scan:PP:Tact}}$. All parameters are based on a free radius sphere fit through the four arcs of measurement points on a test sphere. Eq. 4 and Eq. 6 provide the formulas for $P_{\text{Size.Sph.Scan:PP:Tact}}$ and $P_{\text{Form.Sph.Scan:PP:Tact}}$. R_i is the radial distance of the i^{th} measurement point to the calculated fit sphere centre, D_{cal} is the calibrated diameter and D_{meas} is the measured diameter.

$$Tij = \max(R_i) - \min(R_i) = P_{Form.Sph.Scan:PP:Tact} \quad \text{(Eq. 4)}$$

$$X = \max\left[abs\left(\max(R_i) - \frac{D_{cal}}{2}\right); abs\left(\min(R_i) - \frac{D_{cal}}{2}\right)\right] \quad \text{(Eq. 5)}$$

$$P_{Size.Sph.Scan:k:Tact} = D_{meas} - D_{cal} \quad \text{(Eq. 6)}$$

4. Verification of a measuring system

The example employed in this section is that of a tactile scanning probing system on a state-of-the-art moving bridge type CMM. The MPE values stated are limited to those of the current standard, being MPE_{Tij} = 2.6 µm and $\text{MPT}_{\tau ij}$ = 55 s. The values listed here are only stringent for acceptance testing and not for reverification testing as in this work. To demonstrate the strength of the implemented verification parameters, multiple measurements were executed. The data is presented in Figure 1.

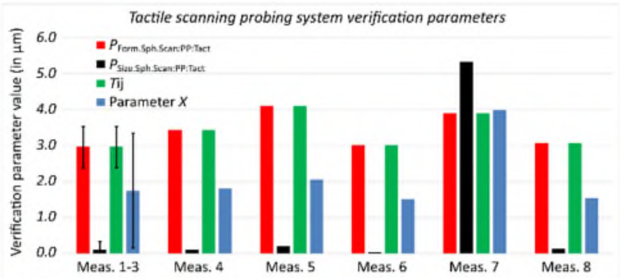

Figure 1. Results for the proposed ($P_{\text{Form.Sph.Scan:PP:Tact}}$ and $P_{\text{Size.Sph.Scan:PP:Tact}}$) and the current (*Tij*, *X*) verification parameters for the experiment.

The first three data sets (meas. 1-3) are acquired with standard settings and procedures. In Figure 1 these three data sets are grouped as one average, including the spread based on the standard deviation multiplied by a Student's t-distribution factor for proper comparison. The values obtained are reasonable, as the measuring system has not been calibrated recently which deteriorates its performance. According to the current standard *Tij* equals approx. 3.0 µm. Parameter *X* equals approx. 1.8 µm. According to the proposed standard $P_{\text{Form.Sph.Scan:PP:Tact}}$ equals approx. 3.0 µm (same as *Tij*) and $P_{\text{Size.Sph.Scan:PP:Tact}}$ equals approx. 0.12 µm. The estimated spread is indicated through the error bars on the first set of measurements. It indicates the instability of *X* from the current standard and considerably smaller spread for the proposed $P_{\text{Size.Sph.Scan:PP:Tact}}$ from ISO/CD 10360-5:2017.

The fourth and fifth set have an intended increasing amount of grease and dirt on the measured artefact and the contact stylus, resulting in deterioration of the verification parameters. It shows primarily in the increase of the measured form error (up to 4.1 µm), which is to be expected due to increased random measurement errors. The sixth is again a clean measurement, where all parameters lower to acceptable values again.

The seventh verification set is done under faulty calibration. This faulty calibration barely influences spread as the surface to be measured is unchanged, smooth and clean. The calibration issue results in a systematic measurement error. This shows in the verification results as an increase in size error ($P_{\text{Size.Sph.Scan:PP:Tact}}$ of about 5.3 µm). The current standard tried to capture this in the second limitation, in this work denoted as parameter *X*. Yet due to its high variability and the influence of random errors it would be hard to detect this increase. $P_{\text{Size.Sph.Scan:PP:Tact}}$ however clearly correlates to the systematic errors in this measurement. The eighth and last verification set is yet again a normal calibration showing a similar, reasonable outcome as before.

5. Conclusion and future work

This paper introduced the proposed ISO/CD 10360-5:2017, focussing on the section that will replace ISO 10360-4:2000. It compared both on a theoretical and an experimental basis. The experiments prove there is increased sensitivity to detect systematic errors and more importantly to separate these from random errors. It distinguishes random effects ($P_{\text{Form.Sph.Scan:PP:Tact}}$ from 3.0 µm to 4.1 µm) and systematic effects ($P_{\text{Size.Sph.Scan:PP:Tact}}$ from 0.12 µm to 5.3 µm) where the current standard fails mostly at the latter. The recent changes are thus necessary. In-depth investigation helps to further improve interpretability and to strengthen the procedures.

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