CMM tactile probe performance evaluation according to ISO/DIS 10360-5:2018

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Abstract

The CMM tactile probe performance evaluation standard ISO 10360-5 is soon receiving an update. The first part of this work scrutinises the changes between the balloted standard ISO/DIS 10360-5:2018 with the standard in effect, ISO 10360-5:2010 and the preceding related standards (ISO 10360-2:2001 and ISO 10360-5:2000).

When comparing the standards with industrially available data sheets it can be noted that not all performance evaluation parameters are included. A second component of this paper quantifies the performance parameters for a state-of-the-art tactile CMM. The performance parameter values – the MPE and the actually measured parameters - are discussed to show the importance of completeness of data sheets and the limitations of the probe performance verification tests.

1 ISO 10360: an update anno 2018

In recent years, two revisions have taken place for standardisation on CMM tactile probe performance verification: in 2010 and in 2017-2018 with the approval of subsequent editions of ISO 10360-5. These turning points have resulted in an improved reproducibility for the performance tests, according to the author.

At first, ISO 10360-5:2010 [1] detailed to a far better extent the performance of tactile probing systems than the preceding related standards. It includes single-stylus and multi-stylus performance procedures after a shift of some portions of ISO 10360-2 to this specific standard part. The reorganisation of the structure emphasized the isolation of the probing system performance [1].

The second reform is very recent as ISO/DIS 10360-5:2018 [2] has only just been balloted. In this, again a segment of the ISO 10360 series is relocated. This time the verification procedures for tactile scanning probing is moved from part 4 to part 5. ISO/DIS 10360-5:2018 thus now contains all tactile probing system verification procedures [3]. The standard components considered in this paper are §6.3 on single-stylus probe verification and §6.6 on articulating multi-stylus probe verification. For the latter the empirical qualification method is investigated. In the empirical qualification method the parameters for each probing system, attached to an articulation system, must be acquired by measuring a reference sphere at each angular position used [2].

The remainder of this section provides details on the ISO/DIS 10360-5:2018 components, which describe performance tests for tactile touch-trigger probing systems that are mounted on a rotary head. Firstly, section 1.1 scrutinises the scope and the technical objectives. Next, section 1.2 elaborates on the changes in annotations and symbols. Lastly, section 1.3 stresses the industrial relevance and the level to which it is currently used in industry.

1.1 Scope and technical objectives of ISO/DIS 10360-5:2018

The introductions of ISO 10360-5:2010 [1] and ISO/DIS 10360-5:2018 [2] state their technical objectives. These objectives are often mistakenly assumed to be further-reaching than is the case. The primary objective of ISO/DIS 10360-5:2018 is to determine the practical performance of a complete CMM and its probing system [1, 2]. The prescribed tests serve to reveal measuring errors, which are likely to occur when such a combined system is used on real workpieces, e.g. errors generated by the interaction between large probe-tip-offset lengths and uncorrected CMM rotation errors [1, 2]. Commonly, the errors within the multi-stylus component of the probe performance are considerably increased when compared to those of the single-stylus component. This is mainly due to the net CMM travel, which can be substantially larger than the measured length, because of the difference in the probing system orientation. Due to the sensitivity to both CMM and probing system errors, the probe performance tests are to be performed in combination with ISO 10360-2:2009. This work thus fits in a larger framework.

This paper includes two tests that apply to all tactile probing systems mounted on a CMM through a rotary head. They are not subsequent steps in the preferential procedure sequence described in literature [3, 4, 5, 6]. The single-stylus segment should be executed before and the multi-stylus segment after the linear dimension verification test of ISO 10360-2:2009.

1.2 Annotation of tactile probe verification parameters

Figure 1 depicts schematically the evolution of the tactile probe verification parameter set and the annotation changes of verification parameters over time. In this context, the MPE value represents the maximum permissible measurement error. Each MPE value of the probe performance parameters is fixed by a positive constant and is usually expressed in micrometres. An example of values for a state-of-the-art CMM with a common tactile probing system can be found in Table 1 of section 3.1.

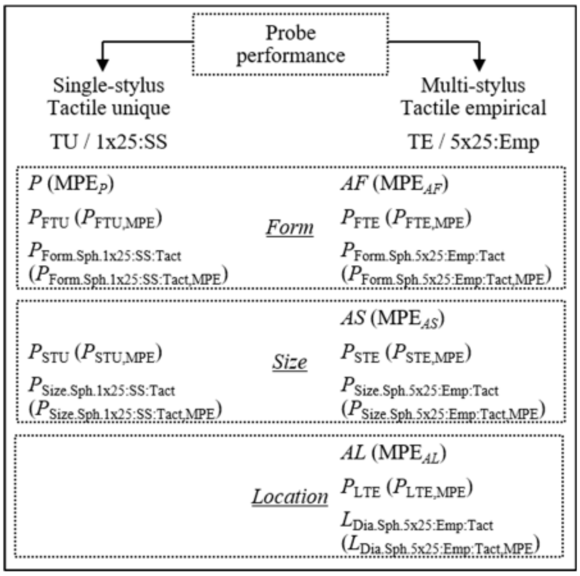

Figure 1: Probe performance parameter evolution

A first branch concerns the single-stylus probe performance. The performance of the probe was addressed with only one parameter in ISO 10360-2:2001, namely the probing error (P). The maximum permissible probing error (MPE$_P$) was for instance provided by the manufacturer. This single parameter gave indication of how the probe performed when measuring a sphere, yet only in terms of spread on the measurement results.

With the update of ISO 10360-5:2010 the standard introduced the single-stylus size error (P_{STU}) that calculates the more systematic errors that result in a size difference between the measured diameter and the calibrated diameter of a test sphere. The probing error (P) was redefined as the single-stylus form error (P_{FTU}). These two parameters (P_{FTU} and P_{STU}) are linked to the single-stylus performance test. The $_{TU}$ qualifier for the verification parameter corresponds to the tactile ($_T$) probing phenomenon and the use of a single or unique ($_U$) stylus.

The newest edition of the standard (ISO/DIS 10360-5:2018) only changed in terms of notation. $P_{Form.Sph.1x25:SS:Tact}$ and $P_{Size.Sph.1x25:SS:Tact}$ correspond to the previously mentioned parameters P_{FTU} and P_{STU} respectively. The qualifiers attached to the probing errors are built up accordingly, referring to the form or size error on a sphere ($_{Sph}$) determined through a single measurement of 25 points in **s**ingle-**s**tylus fashion with at tactile probe ($_{1x25:SS:Tact}$).

The other branch contains the multi-stylus probe performance. ISO 10360-5:2000 defined and tested parameters to express the performance of an articulating probe (AF, AS and AL) yet they were not always given in manufacturer specifications.

ISO 10360-5:2010 renamed these parameters for form ($_F$) error, for size ($_S$) error and for location ($_L$) value in combination with an acronym that indicates the type of multi-stylus probing. This paper focusses on a tactile ($_T$) probing system with an empirical ($_{\mathrm{E}}$) qualification of the articulating-based multi-stylus probing system. This leads to the multi-stylus form error (P_{FTE}), the multi-stylus size error (P_{STE}) and the multi-stylus location value (P_{LTE}).

The last revision (ISO/DIS 10360-5:2018) again primarily changed the notation. $P_{\mathrm{Form.Sph.5x25:Emp:Tact}}$, $P_{\mathrm{Size.Sph.5x25:Emp:Tact}}$ and $L_{\mathrm{Dia.Sph.5x25:Emp:Tact}}$ will replace the notation P_{FTE}, P_{STE} and P_{LTE}. The qualifier of the last revision contains reference to sphere measurement using five measurement orientations, each taking 25 measurement points where the tactile probing system uses empirical qualification ($_{\mathrm{Sph.5x25:Emp:Tact}}$).

1.3 Industrial relevance and usage

This paper describes the theoretical and practical aspects of the updated standard. The parameter set provides detailed insight in how a probe performs and where the problem might originate if the parameter values are found to be excessive.

The single-stylus form error can be correlated to e.g. probing direction dependencies and the probe's random errors on a single measurement point. The single-stylus size error on the other hand can detect systematic errors in e.g. the probing compensation determined by the qualification. The results of the single-stylus test detail probing behaviour when using a single orientation for smaller features or objects and can also be used to estimate expected measurement errors for such measurements.

The multi-stylus form and size error similarly detect errors of the probing system, but only when employing multiple sensor orientations within a single assessment. The location value can indicate errors to be expected for nearby features when those features cannot be accessed by a single probing orientation. The latter is closely linked to the net CMM travel and thus the linear dimension test, even more so for features that are more distant to one another.

Lastly one of the aims of this work is to introduce the new standard within the CMM dimensional metrology community with as goal to speed up acceptance and adoption of the new protocols within both manufacturer data sheets and measurement reports.

2 Measurement procedure

This section deals with most aspects of the procedural specifications for the single-stylus and multi-stylus tactile probe verification tests. Within the procedure the operating conditions provided with the MPE statements must be followed. This includes the prescribed start-up and warm-up cycle, the limitations of the stylus configuration and assembly, the cleaning procedures and the qualification of the system. The CMM investigated in this work is equipped with an articulation actuator that uses the empirical qualification method. In section 2.1 the measurement artefact and the test setup are described. In section 2.2 the data acquisition is discussed and in section 2.3 the parameter determination.

2.1 Measurement artefact and test setup

The measurement artefact is a spherical material standard of size, with a nominal diameter of 30 mm (between 10 mm and 50 mm [2]) and is further denoted as the test sphere. The form error of the artefact is below 0,2 µm according to its calibration certificate, which is smaller than the recommended maximum value of 0,34 µm, being 20% of the MPE value for the single-stylus probing form error ($P_{\mathrm{FTU,MPE}}$) being tested [2]. The sphere used for probing system qualification (i.e. the reference sphere), is a similar object with a nominal value of 19 mm.

The set-up is depicted in Figure 2. The qualification sphere (left, 19 mm) is further back in the measuring volume than the test sphere (right, 30 mm). Using a different part of the measuring volume for the qualification and the verification ensures the incorporation of measuring volume dependent aberrations in the test.

The stylus choice is mainly crucial for the multi-stylus test, as the stylus tip offset of the tactile probe is a direct influencer of the CMM's net travel throughout the test. A stylus with 3 mm diameter ruby ball tip and limited length of 20 mm has been selected and utilised for both tests to reduce the effect of the length measurement error E_{L}.

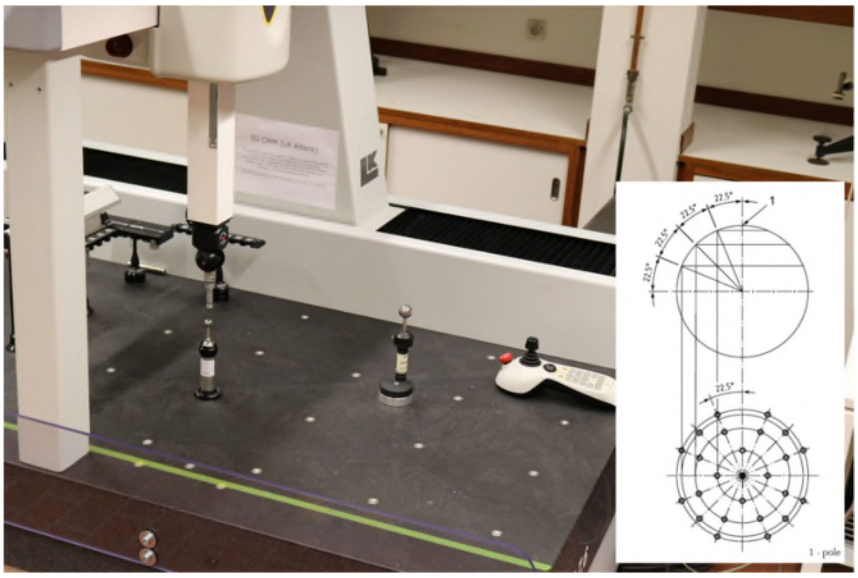

Figure 2: Tactile probe verification test setup and sphere probing pattern

2.2 Data acquisition

The single-stylus verification contains a single sphere measurement, where the multi-stylus verification employs five sphere measurements on the artefact from different probing directions [1, 2]. The main orientation (used in both tests) is parallel to the ram axis *z*, which in this case is a vertical probe orientation. For the multi-stylus test, the standard describes the preferred five angular positions for the articulator. Next to the main orientation it employs four orientations that are perpendicular to the main one (i.e. horizontal) and 90° oriented with one another.

All five positions are used to acquire 25 measurement points on a hemisphere of the artefact. The probing pattern is displayed in the bottom right corner of Figure 2. It contains the pole, 16 points on three levels (4-8-4 distribution) and 8 points on the equator. The levels correspond to polar coordinates of 0° (pole), 22,5°, 45°, 67,5° and 90° (equator). The points within one level are equally spaced and the spread over different levels strive for a quasi-evenly distributed point set. The probing pattern is always oriented to assure that the sphere centre and the pole of the point set form a line parallel to the orientation of the probe.

2.3 Parameter determination

The single-stylus probe verification only uses the 25 measurement points of the main vertical orientation. A Gaussian least-squares free-radius sphere fit is computed. The form and size error of this sphere fit is examined to yield the parameters P_{FTU} and P_{STU} (respectively $P_{\mathrm{Form.Sph.1x25:SS:Tact}}$ and $P_{\mathrm{Size.Sph.1x25:SS:Tact}}$).

The Gaussian radial distance to the centre of the fitted sphere, R_{i}, is calculated for each individual measurement point. The range of R_{i} corresponds to the single-stylus form error P_{FTU} and is determined as in Eq. 1 [1, 2]. The diameter of the Gaussian least-squares free radius fit, $D_{\mathrm{meas,TU}}$, is compared to the calibrated diameter value D_{cal}, using Eq. 2. This yields the single-stylus size error P_{STU}.

$$P_{\mathrm{FTU}} = P_{\mathrm{Form.Sph.1x25:SS:Tact}} = \max(R_{\mathrm{i}}) - \min(R_{\mathrm{i}}) \qquad \text{(Eq. 1)}$$
$$P_{\mathrm{STU}} = P_{\mathrm{Size.Sph.1x25:SS:Tact}} = D_{\mathrm{meas,TU}} - D_{\mathrm{cal}} \qquad \text{(Eq. 2)}$$

The multi-stylus probe verification uses all five sets of 25 measurement points, acquired with different probing orientations. A Gaussian least-squares free-radius sphere fit is computed through the full dataset of 125 measurement points. Its form error and size error are examined to yield two out of three parameters of interest, namely P_{FTE} and P_{STE} (respectively $P_{\mathrm{Form.Sph.5x25:Emp:Tact}}$ and $P_{\mathrm{Size.Sph.5x25:Emp:Tact}}$).

The Gaussian radial distance to the centre of the fitted sphere, R_{i}, is calculated for each of the 125 individual measurement points and the range thereof corresponds to the multi-stylus form error P_{FTE}. Again also the diameter of the Gaussian least-squares free radius fit, $D_{\mathrm{meas,TE}}$, is compared to the calibrated diameter value D_{cal}, leading to the multi-stylus size error P_{STE}. The equations are analogue to Eq. 1 and Eq. 2 respectively.

Lastly, the location value is determined. For this an unconstrained least squares sphere fit is performed on the data of each measurement orientation separately, thus based on 25 measurement points each. The centre points of the five resulting sphere fits are obtained and then evaluated. The probing system's multi-stylus location error P_{LTE} (or $L_{\mathrm{Dia.Sph.5x25:Emp:Tact}}$) is the diameter value of the minimum circumscribed sphere encompassing all centre points.

3 Probe verification parameter MPE values and results

This section elaborates on a verification test conducted on a state-of-the-art CMM equipped with a common tactile probing system. In section 3.1 the MPE values specified by the manufacturer are first given. For the verification tests described here, which are not acceptance tests, these MPE values are indicatory rather than stringent. In section 3.2 the results obtained when conducting the verification are reported and discussed. In section 3.3 these results and conclusions are put in perspective with respect to actual measurements.

3.1 Probe verification parameter MPE values

The CMM tested is an LK Altera 15.7.6 CMM acquired in 2015. The probing system is a Renishaw TP200 tactile touch-trigger probe. For completeness the stylus choice with $L = 20$ mm and $D = 3$ mm is repeated. The test sphere has a calibrated diameter of 29,9987 ± 0,0011 mm.

The probing performance MPE values are given in Table 1 (together with the verification results). The manufacturer data sheet that contains the MPE values is based on the 2010 standard, and is not entirely complete; the single-stylus size error (P_{STU}) is not specified.

It is clear from the MPE values that the single-stylus probe performance is expected to be more accurate than the multi-stylus probe performance. This is evidently linked to the increased machine volume usage and the utilisation of the rotation actuator, which both introduce an extra uncertainty.

Table 1: MPE and performance values for the tactile probing performance evaluation of an LK Altera 15.7.6 CMM with a TP200 tactile probe

Performance specifications and results in µm		Form	Size	Location
Single-stylus	MPE value	1,70	/	n/a
	Performance value	1,30	0,09	n/a
Multi-stylus	MPE value	6,00	4,00	6,00
	Performance value	7,80	0,78	3,60

3.2 Probe verification parameter results

The results of the probe performance verification test are listed in Table 1. The overall trends are for the greater part in line with both the provided MPE values and with the experience of utilising the CMM.

The single-stylus probe performance is within limits, when comparing the P_{FTU} of 1,30 µm to the $P_{FTU,MPE}$ of 1,70 µm. The P_{STU} is limited to 0,09 µm. This shows proper functioning of the stylus system in a single orientation measurement.

The multi-stylus probe performance is less precise as expected. The multi-stylus form error P_{FTE} reaches 7,80 µm and is the only parameter that exceeds its MPE value of 6,0 µm. Measuring the form of a feature employing multiple probe orientations thus renders enlarged errors originating from the measuring system.

This is also visible in the P_{LTE} value of 3,60 µm. This value stays within the MPE-bound of 6,0 µm. Utilising multiple sensor orientations for a sphere measurement leads to centre offsets of a considerable size, certainly when taking into account the fact that the centre determination averages out a large portion of the random error as these are based on 25 measurement points each. The multi-stylus size error P_{STE}, the last parameter verified, is 0,78 µm and performs better than the MPE value of 4,0 µm. The increase when compared to its single-stylus counterpart however is obvious.

3.3 Influence on practical measurements

The results from the probe performance tests follows the knowledge at hand from experienced users of CMMs. It has been long known that using a single probe orientation yields better results. The performance testing now also provides indicatory values that quantify this difference in accuracy.

Nevertheless it has to be remembered that the performance tests have a limited scope and its results only reflect a specific type of measurements. The tests described here are restricted to measurements on a spherical material standard of size. This means that the object under investigation for these tests is close to ideal. The sphere roundness (sphericity), the surface characteristics and feature accessibility can be disproportionally well-defined when comparing them to real workpieces. Also the fact that spheres are ideal objects to measure and the determination of centre and size easily renders stable results should be taken into account.

The use of the probe performance tests thus make it possible to verify whether the probing system is working as intended, yet does not guarantee the measurements conducted with this probing system are of the same quality. However it forms a sound basis for comparing the performance of different CMMs.

4 Conclusion

This paper elaborated on the probe performance evaluation tests for a tactile CMM probing system. The first section detailed to a great extent the evolution of the standard addressing this matter throughout its editions (ISO 10360-5:2000, ISO 10360-2:2001, ISO 10360-5:2010 and ISO/DIS 10360-5:2018).

The second part elaborated on the test procedure in terms of the measurement artefact, the test setup, the data acquisition and the parameter determination.

The third portion then showed results of these verification tests on a state-of-the-art tactile CMM and put them in perspective using the MPE values gathered from the data sheet at hand. The results proved proper functioning of the probing system of this CMM, yet indicated an underestimation of the multi-stylus probing form error P_{FTE}. The discussion following this comparison indicated the relevance and level of usefulness to practical measurements with such a measuring system.

References

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