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Influence of touch speed and measurement strategy on CMM probe qualification uncertainty*

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The aim of this paper is to evaluate, for several probe configurations of a Coordinate Measuring Machine (CMM), the levels of touch speed and measurement strategy factors that enable to minimize the Type-A probe qualification uncertainty.

The statistical methodology adopted to analyse the experimental results is based on Levene Test for homogeneity of variances.

1. INTRODUCTION

In CMM there are many error components that lead uncertainties, [1]. This paper deals with the probing system error related to tip diameter, caused by signal acquisition delay and structural yelding of the stylus. The procedure usually supplied by CMM manufacturers to evaluate the dynamic diameter of the tip is the probe qualification.

To minimize such error source, it is necessary to reduce the uncertainty related to probe qualification procedure. The aim of this paper is to evaluate, for ten different probe configurations, the levels of touch speed and measurement strategy factors that enable to minimize the Type-A probe qualification uncertainty.

The experimental tests are carried out on a DEA Brown & Sharpe Mistral in the Metrology Laboratory of Department of Mechanical Engineering at University of Salerno.

2. PROBE QUALIFICATION AND EXPERIMENTAL DESIGN

The probe qualification procedure consists in measuring a small number of points on a precision calibrated spherical artifact and fitting a least-squares sphere to the measured points. The least-squares radius of the measured sphere is the sum of the radius of the artifact and the effective radius of stylus ball. Subtracting the radius of the artifact it yields an estimate of the dynamic stylus ball radius, [2].

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To start the probe qualification, the operator chooses the probe configuration factors (stylus length, nominal tip diameter, pitch and roll angles), the kinematic factors (move speed, touch speed and approach distance) and the measurement strategy factors (number of hits, number of levels, start and end angles).

The probe orientation is defined in term of pitch and roll angles. These angles are the rotation of the tip, respectively, in the vertical and horizontal directions. The approach distance defines the span from the instant the speed changes from move speed to touch speed before contacting the surface. The measurement strategy is defined in terms of total number of hits to touch in a fixed number of levels. Each level is a parallel circle of the calibration sphere; the parallels are equally spaced between start and end polar angles.

Table 1 summarizes the levels of probe configuration factors adopted in this experimental study. In practice, these factors are related to real workpiece geometry.

The kinematic and measurement strategy factors can be chosen freely from the operator. We adopt an approach distance equal to 5 mm, to guarantee a constant contact speed without dumped oscillations, and a move speed equal to 250 mm/s, the maximum move speed of CMM. We suppose that the operator can choose two different touch speeds equal to 1% and 5% of maximum move speed. We code these values as 1 and 5. We assume that the operator can choose two different strategies: five points on two levels (four points on the equator and one polar point); twenty-five points on four levels (ten points on equator, nine points on parallel circle with polar angle equal to 60°, five points on parallel circle with polar angle equal to 30°and one polar point). We code these strategies, respectively, as –1 and 1. The start and end polar angles are set, respectively, equal to 0° and 90°. We code the four possible combinations of touch speed and measurement strategy as: <touch speed code>_<strategy code>. We name touch speed and measurement strategy factors as control factors (CF).

To realize the aim of this experimental study, for each probe configuration, we replicate fifty times, in a random order, the probe qualification for each combination of CF, for a total of forty experimental runs.

For each experimental run, by (1), it's possible to estimate the mean ($\overline{x}$), the experimental variance (s^2), the experimental standard deviation (s) and the Type-A standard probe qualification uncertainty (u), [3].

$$\overline{x} = \frac{\sum_{i=1}^{n} x_i}{n};\; s^2(x) = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2;\; s(x) = \sqrt{s^2(x)};\; u(x) = \frac{s(x)}{\sqrt{n}} \tag{1}$$

To compare the experimental variances of several experimental runs, we adopt the Levene test for homogeneity of variances, [4].

Table 1

Levels of ten probe configurations factors

	1	2	3	4	5	6	7	8	9	10
Nominal tip diameter [mm]	2	2	2	2	2	4	4	4	4	4
Stylus length [mm]	20	20	20	20	20	20	20	20	20	20
Pitch angle [degree]	0	45	45	45	45	0	45	45	45	45
Roll angle [degree]	0	45	135	225	315	0	45	135	225	315

3. ANALYSIS OF RESULTS

For each tip diameter and probe configuration there is a statistically significant difference, at the 95% confidence level, amongst the experimental variances relative to the four combinations of CF. So, for each tip diameter and probe configuration, the choice of CF weighs significantly on the variance of dynamic diameter and, so, on the relative uncertainty.

Moreover, for each tip diameter and combination of CF, we cannot reject, at the 95% confidence level, the null hypothesis of homogeneity of variances relative to different probe configurations. Therefore, to evaluate a better estimate of experimental variance for each tip diameter and combination of CF, we pool together (arithmetic mean) the corresponding experimental variances relative to five different combination of pitch and roll angles.

Also in term of experimental pooled variances, for each tip diameter, there is a statistically significant difference, at 95% confidence level, amongst the experimental pooled variances relative to the four combination of CF. Figure 1 plots the experimental pooled standard deviations for tip diameters (tp) equal to 2 and 4 mm.

For each tip diameter and combination of CF, the square root of ratio between the corresponding pooled variance and five times the number of replication in each experimental run, gives the Type-A standard uncertainty of the mean dynamic diameter. Table 2 summarizes these values.

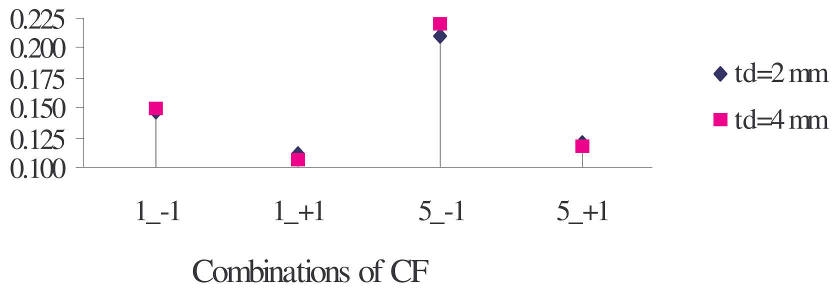

Figure 1. Experimental pooled standard deviation plots for two tip diameters (td).

Table 2
Type-A standard uncertainty [mm]

Tip diameter [mm]	Combinations of CF			
	1_+1	5_-1	5_+1	5_+1
2	0.0093	0.0070	0.0133	0.0076
4	0.0094	0.0066	0.0139	0.0074

The worse combination is 5_-1; the best are 1_+1 and 5_+1. In practice, the measurement strategy with the higher number of probing points (code +1) is more robust to change in touch speed. On the contrary, if we select the measurement strategy with the least number of probing points (code –1), there is a significant worsening of uncertainty in comparison with the change in touch speed from the low level (code 1) to the high level (code 5).

Practitioners usually select the combination 1_-1, that is, usually, the default combination in probe qualification procedure. This combination is not the fittest in terms of uncertainty.

4. CONCLUSIONS

The experimental study carried out in this paper allows quantifying the Type-A probe qualification uncertainty and shows that, for a fixed probe configuration, the touch speed and the measurement strategy weigh significantly on it. Moreover, for each combination of touch speed and measurement strategy, to evaluate a better estimate of Type-A probe uncertainty, it is possible to pool together the experimental variances relative to different probe orientations. The results shows that, for the levels of touch speed and measurement strategy taken in consideration, the measurement strategy with the higher number of probing points is more robust, in term of uncertainty, in comparison with the change in touch speed. On the contrary, the measurement strategy with the least number of probing points is more sensitive in comparison with the change in touch speed; in fact, if we increase the touch speed, we have a significant worsening of uncertainty.

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