ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 63 (2013) 547 – 555
Procedia Engineering
www.elsevier.com/locate/procedia

The Manufacturing Engineering Society International Conference, MESIC 2013

Precision study of a coordinate measuring machine using several contact probes

I. Puertas[a,]*, C.J. Luis Pérez[a], D. Salcedo[a], J. León[a], R. Luri[a], J.P. Fuertes[a]

[a]*Mechanical, Energetics and Materials Engineering Department, Public University of Navarre, Campus de Arrosadía s/n, 31006, Pamplona, Navarra (Spain)*

Abstract

In this research work, a comparative study between the precision obtained with a touch probe (TP-200) and that obtained with a scanning probe (SP-25) is carried out for a specific coordinate measuring machine (CMM). These two types of probes cover the most commonly used contact probes in CMMs, where touch probes work by making contacts with the part and scanning probes maintain the contact with the part as they scan along its surface. In order to do this, one part was manufactured by machining and a series of measurements were taken over it at distinct locations in the CMM working volume. This part consists of parallel planes with different height values (70 mm, 45 mm, 25 mm and 10 mm) from the horizontal plane located on the granite table. The above-mentioned part was measured at five different locations distributed along the working volume and the measurements were repeated three times, where all of them were taken at a temperature of 20 ºC ± 1 ºC. Moreover, not only the CMM uncertainty is taken into account but also the variability associated with the manufactured part along with the measuring process of it.

Selection and peer-review under responsibility of Universidad de Zaragoza, Dpto Ing Diseño y Fabricacion

Keywords: CMM; Uncertainty; Precision

1. Introduction

Dimensional precision of manufactured parts is a matter of the greatest importance, especially in cases where these are to be in contact with each other. Measuring with precision is imposed by the need for manufacturing

* Corresponding author. Tel.: +34-948-169305; fax: +34-948-169099.
E-mail address: inaki.puerta@unavarra.es

Selection and peer-review under responsibility of Universidad de Zaragoza, Dpto Ing Diseño y Fabricacion
doi:10.1016/j.proeng.2013.08.260

products within tolerances. Moreover, in order to guarantee precision in any result, it is necessary to ensure traceability where this implies determining the uncertainty of the measurements (see Aggogeri et al. (2011), Feng et al. (2007) and Barini et al. (2010)).

Generally speaking, coordinate measuring machines (CMM) represent one of the most accurate and flexible measuring instruments used in the metrology field. These are the main reasons why they have become widespread throughout manufacturing companies. Therefore, with this kind of measuring device, it is possible to carry out measurements with a high degree of precision for manufactured parts of practically any type of shape and size (see Hocken and Pereira (2012)).

There are several basic CMM configurations such as: moving bridge type, fixed bridge type, column type, cantilever type, horizontal arm type and gantry type, among others (see AENOR (2001)). This precision study is to be carried out on a moving bridge CMM since it is the most widely used type. Nevertheless, the present study can be applied to any kind of CMM configuration. Furthermore, when the precision of a particular CMM is going to be evaluated, one of the most important aspects to take into account is the type of probe to be utilized. Although a great variety of probes exist, these can be divided into two different categories: contact and noncontact probes. Nowadays, contact probes continue to be the most popular and widespread in CMMs because of their precision and that is the main reason why two of them have been selected to make this comparative study of precision.

So, the main aim of this work is to carry out a comparative study between the precision obtained with a touch probe (TP-200) and that obtained with a scanning probe (SP-25). These two types of selected probes cover the most commonly used contact probes in CMMs. In order to do this, one part was machined and measured several times at distinct locations in the CMM working volume. All the measurements were taken at a reference temperature of 20 ºC ± 1 ºC. Moreover, not only the CMM uncertainty (which is of 1.7 μm + 3L/1000 μm) was taken into account but also the variability associated with the measuring process.

2. Equipment description

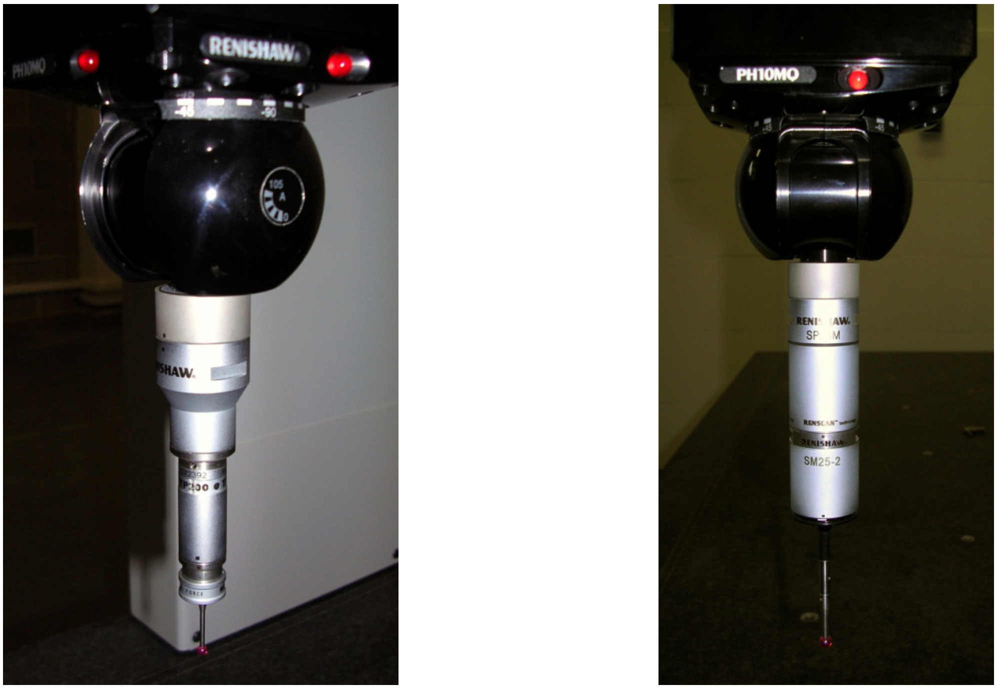
As was mentioned above, the coordinate measuring machine used in the present study was of the moving bridge type. Fig. 1 shows a picture of the CMM, where it can be observed that this type of CMM has a stationary table, made of granite, which supports the part to be measured.

Fig. 1. Moving bridge coordinate measuring machine used in the present study.

Some of the advantages that this CMM configuration presents are as follows: higher natural frequencies (if it is compared to cantilever configuration), small to medium measuring range and relatively small measuring uncertainties (Hocken and Pereira (2012)). On the other hand, due to the yawing effect, which is caused when the two CMM columns move at different speed values, the bridge can twist, thus affecting both the CMM accuracy and precision.

The CMM used in this precision study, which belongs to the Public University of Navarre, is a DEA Global Image Clima. It has an articulated probe head of type PH10MQ and the measuring software is PC-DMIS™ 3.7. As was mentioned above, the standard uncertainty of the CMM is given by: $u_{CMM} = (1.7 + 3L/1000)$ µm, where L is the length being evaluated, and its measuring volume is as follows: 850 mm (X) x 1460 mm (Y) x 780 mm (Z).

The two contact probes whose performances are to be compared in this present study are TP-200 and SP-25, which can be observed in Figs. 2 (a) and 2 (b), respectively.



(a) (b)

Fig. 2. Renishaw® contact probes utilized in the present precision study: (a) TP-200; (b) SP-25.

TP-200 is a precision touch-trigger probe manufactured by Renishaw® which uses strain gauge technology, thus giving a higher accuracy than kinematic touch-trigger probes. The stylus module is mounted on the probe via a highly repeatability magnetic kinematic joint, providing rapid stylus changing capability and overtravel protection. With respect to the length of the stylus employed, this was 20 mm and the tip was a ruby ball with a diameter of 3 mm (see Renishaw's TP200 specifications).

Also manufactured by Renishaw®, SP-25 actually provides two sensors in one as it enables scanning and touch-trigger probes in a single system. Its transducer system consists of a pair of infrared beam sources (IREDs), a pair of light sensitive position sensing devices (PSDs), a pivot spring motion system and an integral pair of reflective concave mirrors. In operation, the IRED beams are directed onto the mirrors and then focused and reflected back onto the PSDs, where they can be translated into spatial measurement coordinates. The stylus length used in this probe was 21 mm and the diameter for its corresponding ruby ball was 5 mm (see Renishaw's SP25 specifications).

Fig. 3. Machined part to be measured with both contact probes: TP-200 and SP-25.

In accordance with Renishaw's probes data sheets and taking their stylus length values into account, we are going to assume that the standard uncertainties values for TP-200 and SP-25 are u_{TP200} = 0.75 µm and u_{SP25} = 0.60 µm, respectively.

In order to carry out this precision study, one part made of aluminium was machined in the shape of a ladder (see Fig. 3).

The ladder to be measured consists of parallel planes with different height values (70 mm, 45 mm, 25 mm and 10 mm) from the horizontal plane, which is located on the granite table of the coordinate measuring machine.

Fig. 4 shows the dimensions of the part in the shape of the straight ladder. The measuring process of the part will be made at five distinct locations.

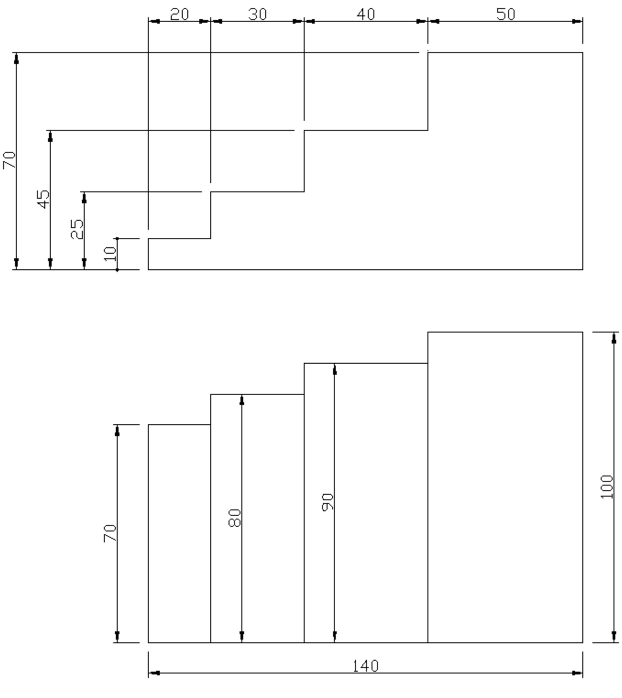


Fig. 4. Size dimensions (in mm) of the straight ladder.

These five locations (identified as "P1" to "P5") are distributed all over the measuring volume of the coordinate measuring machine as follows: "P1" represents the position at the centre, "P2" represents the position at the closer right corner, "P3" represents the position at the closer left corner, "P4" represents the position at the further right corner and, finally, "P5" represents the position at the further left corner of the measuring volume of the CMM. The part will be measured three consecutive times at every position by using both the SP25 and the TP200 touch probes. The measuring points taken by both probes over the part are the same in each of the measured positions.

Furthermore, when defining the geometric planes of the part to be measured, a minimum number of three contacts per plane are required on the surface. In order to analyse the influence of such a number of contacts over the precision in the measuring process, these elements will be defined from three, four and five contact points.

3. Uncertainty analysis

In order to carry out the uncertainty analysis in the case of the measuring process of the straight ladder, the recommendations set out in Guide to the Expression of Uncertainty in Measurement (ISO (1995)) were followed, these leading to Equation 1.

$$u_{part}^2 = u_{\bar{x}}^2 + u_{CMM}^2 + u_{probe}^2 \quad (1)$$

Where u_{part} is the uncertainty of the measured dimension of the part, $u_{\bar{x}}$ is the standard deviation of the mean distribution (which, in this case, is equal to the standard deviation of the measurements divided by $\sqrt{3}$), u_{CMM} is the uncertainty of the coordinate measuring machine (defined in Section 2) and u_{probe} is the uncertainty of the used probe, that is to say, TP-200 or SP-25. Although the uncertainty of the measured dimensions is only based on three repetitions, in previous analyses, it has been seen that the use of more repetitions leads to similar results and therefore, it has been carried out in this way so as to simplify the statistical calculations.

Once the uncertainty has been evaluated by the procedure described previously, it is possible to assign a coverage factor (k) so that the so-called expanded uncertainty (U) is evaluated by Equation 2.

$$U_{part} = k \cdot u_{part} \quad (2)$$

This coverage factor k is a numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty, that is to say, a quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand. This fraction may be viewed as the coverage probability or confidence level of the interval. In this study, a coverage factor of k equal to 2 was selected, which produces an interval having a confidence level of 95.45 %, if a normal distribution is assumed.

Table 1. Mean and expanded uncertainty values of the measurements carried out on the straight ladder with TP-200 probe, where P1 to P5 are the CMM positions defined in Section 2 and D1 to D4 are the measured dimensions (expressed in mm).

TP-200 (planes defined with 3 points)					
	P1	P2	P3	P4	P5
D1 (mm)	70.082 ± 0.005	70.080 ± 0.005	70.075 ± 0.005	70.076 ± 0.005	70.081 ± 0.007
D2 (mm)	45.268 ± 0.005	45.264 ± 0.005	45.262 ± 0.005	45.261 ± 0.004	45.264 ± 0.005
D3 (mm)	25.198 ± 0.004	25.198 ± 0.004	25.199 ± 0.004	25.195 ± 0.005	25.199 ± 0.005
D4 (mm)	10.229 ± 0.004	10.229 ± 0.004	10.232 ± 0.004	10.226 ± 0.004	10.230 ± 0.005
TP-200 (planes defined with 4 points)					
	P1	P2	P3	P4	P5

D1 (mm)	70.074 ± 0.005	70.070 ± 0.005	70.073 ± 0.005	70.071 ± 0.005	70.071 ± 0.005
D2 (mm)	45.258 ± 0.005	45.252 ± 0.005	45.254 ± 0.005	45.255 ± 0.005	45.253 ± 0.004
D3 (mm)	25.199 ± 0.004	25.192 ± 0.004	25.195 ± 0.004	25.195 ± 0.004	25.192 ± 0.004
D4 (mm)	10.228 ± 0.004	10.220 ± 0.004	10.225 ± 0.004	10.226 ± 0.004	10.221 ± 0.004
TP-200 (planes defined with 5 points)					
	P1	P2	P3	P4	P5
D1 (mm)	70.095 ± 0.005	70.096 ± 0.005	70.100 ± 0.005	70.093 ± 0.005	70.096 ± 0.005
D2 (mm)	45.254 ± 0.005	45.255 ± 0.005	45.257 ± 0.005	45.253 ± 0.005	45.256 ± 0.005
D3 (mm)	25.191 ± 0.004	25.189 ± 0.004	25.190 ± 0.004	25.191 ± 0.005	25.194 ± 0.005
D4 (mm)	10.224 ± 0.004	10.221 ± 0.004	10.222 ± 0.004	10.224 ± 0.004	10.231 ± 0.004

Tables 1 and 2 show the mean and the expanded uncertainty values of the measurements obtained in the case of the straight ladder when using TP-200 and SP-25, respectively. As was mentioned above, when defining the planes of this ladder, three, four and five contact points were taken. “D1” to “D4” represent the distances between each plane of the ladder and the horizontal plane of the CMM located on the granite table. The values of the extended uncertainty were rounded up to three significant figures.

Table 2. Mean and expanded uncertainty values of the measurements carried out on the straight ladder with SP-25 probe, where P1 to P5 are the CMM positions defined in Section 2 and D1 to D4 are the measured dimensions (expressed in mm).

SP-25 (planes defined with 3 points)					
	P1	P2	P3	P4	P5
D1 (mm)	70.070 ± 0.005	70.069 ± 0.005	70.071 ± 0.005	70.070 ± 0.005	70.073 ± 0.005
D2 (mm)	45.259 ± 0.004	45.258 ± 0.004	45.260 ± 0.004	45.259 ± 0.004	45.260 ± 0.004
D3 (mm)	25.194 ± 0.004	25.192 ± 0.004	25.193 ± 0.004	25.193 ± 0.004	25.194 ± 0.004
D4 (mm)	10.227 ± 0.004	10.226 ± 0.004	10.224 ± 0.004	10.226 ± 0.004	10.225 ± 0.004
SP-25 (planes defined with 4 points)					
	P1	P2	P3	P4	P5
D1 (mm)	70.060 ± 0.005	70.054 ± 0.005	70.062 ± 0.005	70.053 ± 0.005	70.059 ± 0.005
D2 (mm)	45.246 ± 0.004	45.248 ± 0.004	45.249 ± 0.006	45.241 ± 0.005	45.246 ± 0.004
D3 (mm)	25.188 ± 0.004	25.184 ± 0.004	25.190 ± 0.004	25.185 ± 0.004	25.187 ± 0.004
D4 (mm)	10.220 ± 0.004	10.215 ± 0.004	10.222 ± 0.004	10.216 ± 0.004	10.216 ± 0.004
SP-25 (planes defined with 5 points)					
	P1	P2	P3	P4	P5
D1 (mm)	70.085 ± 0.005	70.090 ± 0.005	70.093 ± 0.005	70.092 ± 0.005	70.085 ± 0.005
D2 (mm)	45.248 ± 0.004	45.251 ± 0.004	45.254 ± 0.004	45.255 ± 0.004	45.248 ± 0.004
D3 (mm)	25.185 ± 0.004	25.186 ± 0.004	25.189 ± 0.004	25.192 ± 0.004	25.184 ± 0.004
D4 (mm)	10.221 ± 0.004	10.219 ± 0.004	10.223 ± 0.004	10.228 ± 0.004	10.219 ± 0.004

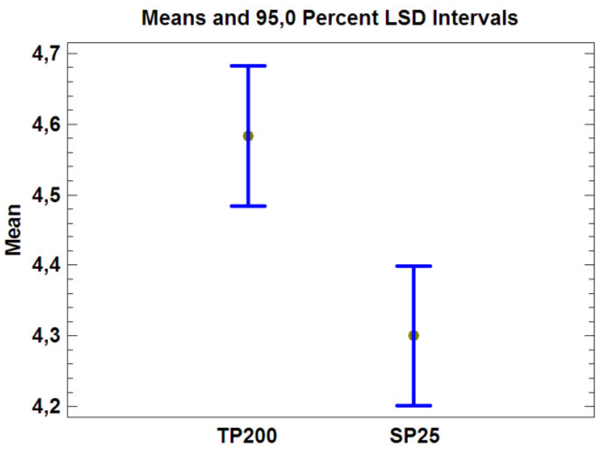


Fig. 5. Plot with the means of the uncertainty values (expressed in µm) for TP-200 and SP-25 and their corresponding LSD intervals (based on Fisher's least significant difference procedure).

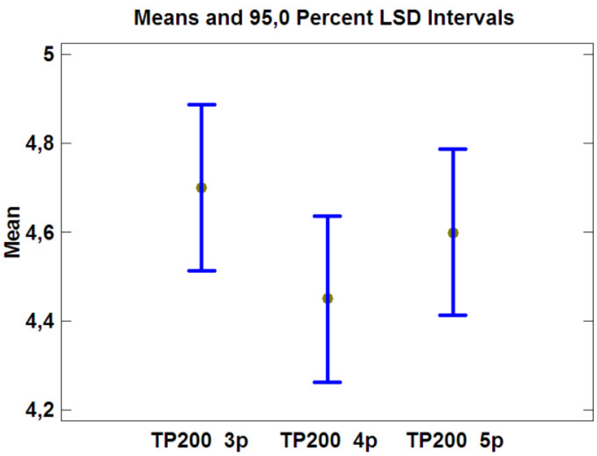


Fig. 6. Plot with the means and LSD intervals of the uncertainty values (in µm) for TP-200 with three, four and five contact points.

Fig. 7. Plot with the means and LSD intervals of the uncertainty values (in µm) for SP-25 with three, four and five contact points.

Table 3. ANOVA table to compare the two samples of uncertainty values for TP-200 and SP-25, where SS is the sum of the squares, DF is the number of degrees of freedom, MS is the mean of the squares, F-ratio is a statistic based on the Fisher-Snedecor distribution function and P-value gives the probability values associated with values which take the variable of a F distribution function.

Source	SS	DF	MS	F-Ratio	P-Value
Between groups	2.4083	1	2.4083	8.08	0.0053
Within groups	35.1834	118	0.2982		
Total	37.5917	119			

In order to determine the homogeneity of the measured data, the multiple sample comparison (MSL) procedure was used. This procedure is designed to compare two or more independent samples of variable data. Tests are run to determine whether or not there are significant differences between the means, variances, and/or medians of the populations from which the samples were taken. The statistical software used in applying this procedure was Statgraphics® Centurion XVI.

When applying the multiple sample comparison procedure to this straight ladder, all the groups of means and uncertainties arranged in positions are homogeneous for a confidence level of 95 %, where this means that the obtained measurements do not depend on the CMM position in any case.

In order to evaluate the performance of both probes when measuring the straight ladder, uncertainty values were grouped into two samples that were compared, showing that SP-25 is more accurate than TP-200, as can be observed in Table 3 and Fig. 5.

Finally, it was considered to be of interest to study the influence of the number of contact points (3, 4 and 5) over the results obtained for the mean and the uncertainty values. To this end, means and uncertainties were grouped into three different samples for each of the two contact probes and all the groups turned out to be homogeneous, this meaning that, in particular, there are no significant differences in the precision of the measurements when three, four or five contact points are used to define the planes of the straight ladder, as can be observed in Figs. 6 (TP-200) and 7 (SP-25).

4. Conclusions

In this research work, a comparative study between the precision obtained with a touch probe (TP-200) and that obtained with a scanning probe (SP-25), both of them from Renishaw®, is carried out for a DEA moving bridge coordinate measuring machine of type Global Image Clima.

In order to carry out this analysis, one part made of aluminium was machined in the shape of a straight ladder to measure distances between planes.

After having measured this part with the two previously-mentioned contact probes, the mean and the expanded uncertainty (following the recommendations set out in the GUM) values of these measurements were calculated. Thanks to the use of the multiple sample comparison procedure, it was possible to study the homogeneity of the measurements at different locations of the measuring volume of the CMM.

In the straight ladder, the precision of the CMM when measuring distances between planes does not depend on the position they were located at, for any of the two used probes and for any of the used contact points (3, 4 or 5).

Furthermore, the performance of the two contact probes turned to be different and the SP-25 probe shows a better performance than the TP-200 probe, which means than the first is more precise than the second.

Finally, it was verified that there were no significant differences in the precision of the measurements when three, four or five contact points were used to define the planes of the straight ladder.

Acknowledgements

The authors acknowledge the support given by the Spanish former Ministry of Science and Technology (now Ministry of Economy and Competitiveness) under the project UNPN03-33-009 and they also acknowledge the support given by the Public University of Navarre.

References

AENOR (Ed.), 2001. UNE-EN ISO 10360-1: Especificación Geométrica de Productos (GPS). Ensayos de Aceptación y de Verificación Periódica de Máquinas de Medición por Coordenadas (MMC). Parte 1: Vocabulario (ISO 10360-1:2000). Asociación Española de Normalización y Certificación, Madrid, Spain.

Aggogeri, F., Barbato, G., Barini, E.M., Genta, G., Levi, R., 2011. Measurement Uncertainty Assessment of Coordinate Measuring Machines by Simulation and Planned Experimentation. CIRP Journal of Manufacturing Science and Technology 4(1), 51-56.

Barini, E.M., Tosello, G., De Chiffre, L., 2010. Uncertainty Analysis of Point-by-Point Sampling Complex Surfaces Using Touch Probe CMMs: DOE for Complex Surfaces Verification with CMM. Precision Engineering 34(1), 16-21.

Feng, C.-X., Saal, A.L., Salsbury, J.G., Ness, A.R., Lin, G.C.S., 2007. Design and Analysis of Experiments in CMM Measurement Uncertainty Study. Precision Engineering 31(2), 94-101.

Hocken, R.J., Pereira, P.H. (Eds.), 2012. Coordinate Measuring Machines and Systems. CRC Press Taylor & Francis Group, Boca Raton, USA.

ISO (Ed.), 1995. Guide to the Expression of Uncertainty in Measurement. International Organization for Standardization, Geneva, Switzerland.

Renishaw, TP200 touching probe specifications. http://www.renishaw.com/en/tp200--6671.
Renishaw, SP25 scanning probe specifications. http://www.renishaw.com/en/sp25m--6688.