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PRINCIPLES FOR SELECTION OF COORDINATE MEASURING MACHINES – A CASE STUDY

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ABSTRACT

In this paper are presented the principles for selecting a coordinates measuring machine in order to accomplish the requirements of the workshop or laboratory where it is used. The present work is structured on two parts according the below presented structure. In the first part are presented the usually criteria for the selection of this machine type, the verification of the measuring uncertainty, the tolerances of the measurements and some final considerations. In the second part is presented the practical realization of two acceptance tests, made on the coordinates measuring machine. The conclusions obtained based on these tests allow to sentence that the coordinates measuring machine functions at the parameters provided by supplier and still may be used for the research work, fully assuring the precision and accuracy demanded by this activity type.

KEYWORDS: coordinate measuring machine, computer aided inspection, ISO 10360-2/2009

1. INTRODUCTION

The quality assurance and control process developed in the machining stage depend by the performances of the coordinate measuring machines (CMM) used in these processes.

For more then 20 years, the coordinate measuring machines replaces the traditional inspecting methods based on calipers, obtaining the decreasing of time and efforts needed for the quality control operations.

The CMM offers not only the capability to inspect standardized geometrical form but also specific forms as teeth, propellers etc.

In a traditional manufacturing environment all these forms needs specialized measuring machines or specialized calipers.

As it is known, the products quality depends not only by the quality of machine-tools used for machining the products, but also by the precision and accuracy of measuring instruments.

As example, a machining center with modest performances, used together with a high-performance CMM may assure a high quality production because only the parts which are inside of the tolerance field will pass the quality control. Contrariwise, a high-performance machining center used in combination with a low level CMM can’t guarantee a quality production. A percent of machined parts, outside of the tolerance field, will pass the quality control and a percent of the good parts will be rejected.

So, the selection of coordinate measuring machines is a critical choice.

1.1. Selection criteria

The first and most used selection criterion is the measuring range required by the dimensions of parts which will be measured on the CMM.

However, the things are not limited to these dimensions. We will have to keep in mind that the maximum measuring range may be bigger than the part’s dimensions if the inspection algorithm needs fasteners with big dimensions.

As principle, we can consider that are enough travels twice as part’s dimensions corresponding to the *X*, *Y* and *Z* axis.

The second selection criterion is the acceptable measuring uncertainty. The uncertainties and methods for testing it are described in the ISO 10360-2 standard. The mentioned standard is in force from

1994 and stipulates two uncertainty types: volume uncertainty (E) and probing uncertainty (R).

1.2. Verification of measurement uncertainty

In order to check the length measurement uncertainty are used a suite of gauge blocks, see figure 1.

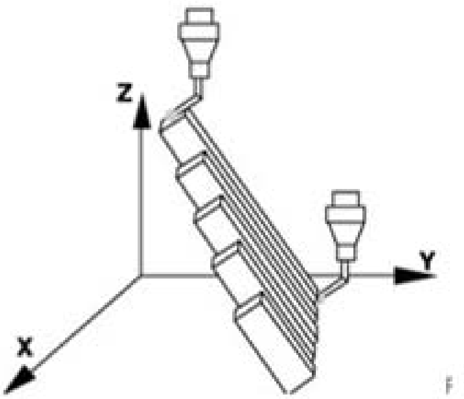

Fig. 1. Length measurement uncertainty

The user selects seven positions in the machine measurement volume. For each of these seven positions, are measured five gauge blocks, each measurement being repeated for three times. In this way are obtained 105 measurements. All these measurements should be inside the tolerance field specified by producer.

In order to check the probing is probed a sphere with diameter between 10 and 50 mm, with form and diameter certified by producer.

The test consists in the probing of 25 points, equal distributed on the sphere's surface, see figure 2. The *R* value is calculated adding to the radius value the minimum and maximum form deviations. The result is expressed in μm and all the 25 results will be considered.

It is important to keep in mind that the CMM's measuring uncertainty, in real operating conditions, may be bigger than those stated by producer. This thing happened due to the using of probe extensions, rotating tables, temperature variation and impurities in the laboratory environment.

Due of these differences in practice it is applied a correction coefficient for the tolerances used to calculate the specifications of a certain CMM.

This coefficient depends on the above presented factors, on the measurement complexity and on the process itself. The usual range is 1:3 to 1:20 with the most common values 1:5 and 1:10.

In order to maintain an uncertainty coefficient of 1:5 for all the part's tolerances, the measuring machine specifications have to be five times more precisely that the tolerance specified for the measured dimension.

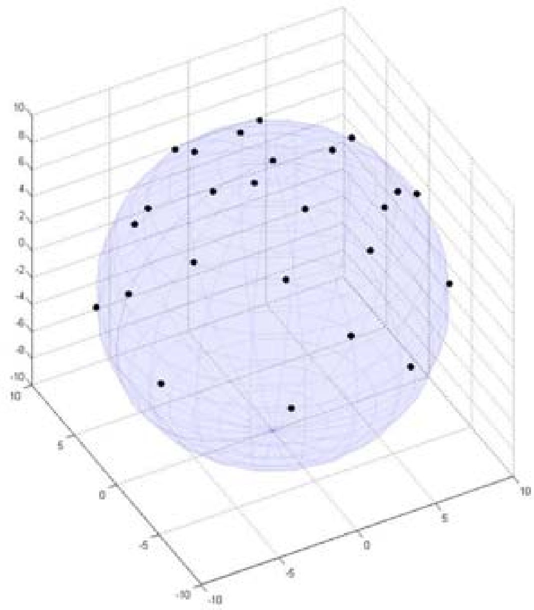

Fig. 2. Points considered for probing test

1.3. Tolerances

For the diameters and lengths tolerances the part's blueprints are analyzed and it is determined the diameter or length with the lower tolerance.

Due to the dependency between the measured length and the volume uncertainty, a larger tolerance of a very length feature may be established more difficult than a smaller tolerance of a shorter feature.

The uncertainty of any CMM depends in great measure by the environment conditions. So, the CMM producers stipulate the temperatures domain, the temperature variation speed and the spatial temperature gradient for which the measuring uncertainty was calculated. These variables should be considered when it is choose a coordinate measuring machine.

More, the ground vibrations have a big influence. The producers specify the maximum level for which the machine may work in acceptable conditions. Optional, can be purchased active or passive damping systems in order to allow the emplacement of CMM in environments less favorable from the vibrations point of view.

If is considered that the vibrations may be a problem it is important to made a study regarding the ground vibration for the CMM emplacement.

1.4. Final considerations

All CMM producers provide software for basic measurement operations. Some of them provide software for complex features as conical gears, rotors, helical compressors, worm mill etc.

Before buy a coordinate measuring machine it is important to be sure that we can appreciate the complexity of measurement operations which will be executed and to choose the most suitable software.

Another reason is the requirement for data transfer. The more parts may be measured with the CMM in a unity of time, the more will be reduced the measurement cost for each part. The acceleration and the number of points probed per minute are parameters which determine the data transfer. The transfer speed may be increased by a convenient emplacement of the measured parts.

2. A CASE STUDY

2.1. Measurement conditions

The measurements were done in the *Calculus and measurements* laboratory, the air temperature being 25,4 °C. It was used a probe with diameter 4 mm and length 25 mm. At probe qualification the form error was 0.005 mm and the diameter error was 0.002 mm.

In order to test the probing errors was used a calibration sphere with diameter 19.050 mm.

The probing reputability stipulated by producer is 0.75 µm.

2.2. Probing acceptance test

On the sphere surface were probed and recorded 25 points, with previously calculated coordinates. In figure 3, it is presented the result of the probing test.

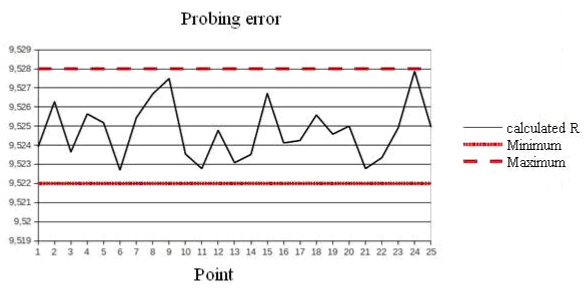

Fig. 3. Error probing test

In the table 1 the maximum and minimum values are presented with bold font.

The domain of the 25 distances doesn't exceed the domain r_{max}-r_{min} stated by producer so the performance of the probing system is considered as checked.

2.3. Acceptance test for length measurement

For this test were used five gauge blocks with nominal dimension: 100; 75; 50; 25 and 20 mm.

According with the producer specifications the thermal expansion coefficient of the gauge material is $11.7 \cdot 10^{-6}$ mm/ºC.

The temperature in the laboratory was 25.5ºC. Although this temperature is different from those recommended by producer (20ºC), which can't be assured, the length error at the gauge block measurement is $6.4 \cdot 10^{-5}$ mm, being negligible in these conditions.

For minimum deviations, the caliber position selections was done according with data presented in table 1.

Table 1. The gauge orientation in the measurement volume

Crt. no.	Selection	Orientation	Contained points
1	Compulsory	Diagonal	(0;0;0) (1;1;1)
2		Diagonal	(1;0;0) (0;1;1)
3		Diagonal	(0;1;0) (1;0;1)
4		Diagonal	(0;0;1) (1;1;0)
5	Optional	Along axis *OX*	(0;1/2;1/2) (1;1/2;1/2)
6		Along axis *OY*	(1/2;0;1/2) (1/2;1;1/2)
7		Along axis *OZ*	(1/2;1/2;0) (1/2;1/2;1)

For each of the seven configurations, the measurements were recorded. Each measurement has three determinations. The 15 measurements of the 5 length corresponding to a position and an orientation are regarded as one configuration.

After complete the test, in the seven configurations, were obtained 105 measurements.

2.4. Result interpretation

For each measurements was calculated the length measurement error E_L. This value is the absolute value of the difference between the indicated value and the value of the gauge length.

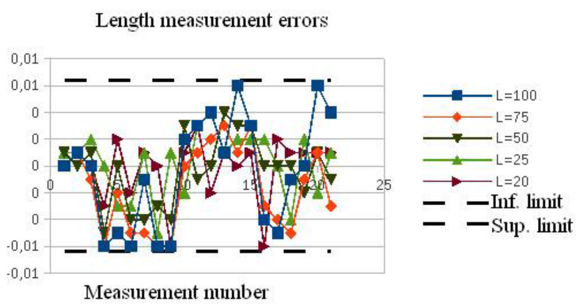

Fig. 4. Verification data

Since the coordinate measuring machine doesn't have devices for compensation of the systematical errors, the value of these errors may not be corrected.

The verification data for each of the seven configurations are presented in figure 4. For each measuring line were made three determinations. The dot lines represent the superior and inferior values of the errors.

The errors of the measurement for each of the 150 measurements are presented in figure 5. The dot lines represent the superior and inferior values of the allowed error. It is obviously that the errors are inside the allowed domain.

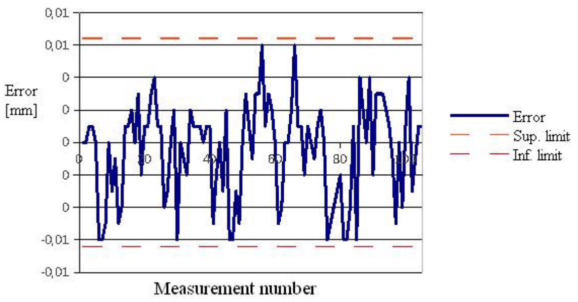

Fig. 5. Errors of measured data

3. CONCLUSIONS

In following is analyzed the repartition of the errors values corresponding to the 105 determinations. These are random errors so it is expectable that their distribution to correspond to the normal distribution, with the average value corresponding to 0.

The obtained data were divided in six intervals, for each interval being counted the errors values. The representation of the errors distribution frequency is presented in figure 6.

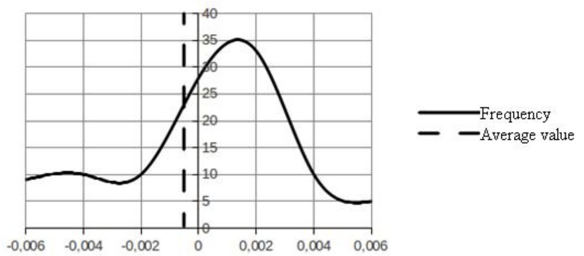

Fig. 6. Errors distribution frequency

Analyzing the diagram we may conclude that it was expected that the error absolute value to depend from the nominal length of the measured gauge. From the diagram 4 it is obviously that this does not happen. The explanation consists in fact that the difference between the gauge lengths is too small to be able to influence the measurement error.

The general trend for error evolution follows the measuring position. This is expectable but not desirable.

The errors distribution is closed enough to the Gauss distribution and the average value of 0.000495 different from theoretical value 0 may be explained by the relative reduced determination number.

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