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Evaluation of the performance of coordinate measuring machines in the industry, using calibrated artefacts

Fernando A. M. Ferreira[a,*], Jesus de Vicente y Oliva[b], Angel M. Sanchez Perez[c]

[a]*CATIM - Technological Center for the Metal Working Industry, Porto, Portugal*
[b]*UPM-ETSII - Technical University of Madrid, Madrid, Spain*
[c]*UPM-ETSII - Technical University of Madrid, Madrid, Spain*

Abstract

The coordinate measuring machines (CMM's) has given a new impulse in the field of geometrical and dimensional metrology. The CMM's in industrial environments have become an important resource for the quality systems, monitoring manufacturing processes, reduction errors during the manufacturing process, inspection of product specifications and in continuous quality improvement. However, there is a need to evaluate, through practical, fast, effective and low cost methods, the CMM metrological specifications. Using calibrated artefacts, able to reproduce the geometric elements frequently measured, it seeks to ensure stability of the functional and metrological characteristics between calibrations and simultaneously knowing the errors. With better monitoring of the control parameters it is possible evaluate and optimize the calibration set deadlines, timely detection of faults and failures, detect structural changes and changes in environmental conditions of the laboratories, thus seeking to conduct a more detailed assessment of the stability of metrological characteristics of a CMM in industrial environments.

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Keywords: Accuracy; Calibrated Artefacts; Evaluation of Industrial Coordinate Measuring Machines; Uncertainty and Principal Influences

[*] Corresponding author. *E-mail address*: fernando.ferreira@catim.pt

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1. Introduction

In general, in industry, when a measurement process, in a coordinate measuring machine (CMM), is well performed and the results obtained are not normal relative to expected, what's happened? We face a problem in production of parts which are out of the specifications, or the CMM is not correctly calibrated?

Nomenclature

α	Coefficient of Thermal Expansion
σ	Standard Deviation
Δt	Difference of the Temperature to 20ºC
a_-	Lower Limit
a_+	Upper Limit
AC	Acceptance Criteria
c	Sensitivity Coefficient
CATIM	Technological Centre for Metal Working Industry
CMM	Coordinate Measuring Machine
DF	Degrees of Freedom
ISO	International Organization for Standardization
L	Length
MPE	Maximum Permissible Error
n	Number of Independent Observations
$u(x)$	Standard Uncertainty
$u(y)$	Standard Uncertainty of Measurement

In many cases, when we need to measure parts with over a thousand characteristics and during the measurement process, when we get results very different from those we expected, which is the procedure that should be taken? What tests we should do? And which the reference standards that we use to confirm the results obtained?

The need for verification of the accuracy of measurement and control equipment is an important prerequisite for quality departments in the industry, since the quality of its production is based on the target of "zero defects", so the need to have a good knowledge about the state of the equipment is extremely important.

In the specific case of the CMM's, in addition to the regular calibration provided in the international standard ISO 10360-2:2009 as a mandatory requirement, the same standard determines the need to make reverification tests, according to the user's specifications, looking for deviations not allowed in their systematic errors.

Also, the international standard ISO 17025:2005 which defines the general requirements for the competence of testing and calibration laboratories, in point 5.5.10 of the technical requirements says that the intermediate checks are needed to maintain confidence in the calibration status of the equipment, these checks shall be carried out according to a defined procedure.

The purpose of this paper is to describes a control method for CMM's between calibrations and/or verifications (intermediary checks) using a special type of calibrated artefacts in a reference CMM with lower uncertainty.

The artefact was designed looking for a dual purpose: to maintain a high metrological quality in order to be certified with low uncertainties while having a relatively high number of geometric features without compromising the geometrical and thermal stability of the artefact.

The ultimate goal is that a relatively high number of metrological tasks could be performed using this artefact, covering most of the tasks that a typical CMM in an industrial environment performs daily.

The purpose was also develop a practical and intuitive, method to evaluate the performance and the conformity of the CMM's in the industry, for operators of such machines can perform rapid and conclusive analysis when will confront doubts about the results of a measurement process.

2. Methodology Procedure – Coordinate measure machine used and new type of artefact

In the coordinate measuring machines world, the most commonly found in industry, laboratories and research centers are the bridge-type CMM's.

Following this work, we used a ZEISS CMM, model UPMC-Ultra, of the CATIM. It's a high accuracy CMM, normally used to support calibration of standards and to support the development of new products with high dimensional and geometric accuracy, and used to measure the new types of calibrated artefacts.

Fig. 1 - ZEISS Coordinate Measuring Machine, Model UPMC Ultra. The main specifications are:
MPE (1/2D) = 0,3 + L/1000 μm, (with L mm) And MPE (3D) = 0,4 + L/1000 μm, (with L in mm).

In the laboratories of the companies is common to find standard parts or some types of artefacts with spheres that can help operators to make a rapid analysis of the state of a CMM.

The dimensional and geometrical tests, evaluate if the results of the measurements of the elements of a standard parts, over time, to monitored the trend and consistency of the CMM.

In some cases, when used a production part as a reference part to perform a measurement routine, we can control and monitored the stability of a CMM. However, in other cases, the type of parts produced is not appropriate to this type of tests, because the dimensional and geometrical characteristics and surface state are not appropriate and forcing to use calibrated artefacts.

2.1 A new type of artefact

The existing artefacts (bars, tables, cubes with spheres, etc.) are expensive and have some limitations when an operator want do a quick and intuitive scan about the dimensions and geometries characteristics obtained in an intermediate check about the state of the CMM.

The work continued initiating the development of a new type of artefact that encompassed the majority of the geometrical elements possible to measure and evaluate in a part, using a high accuracy coordinate measuring machine.

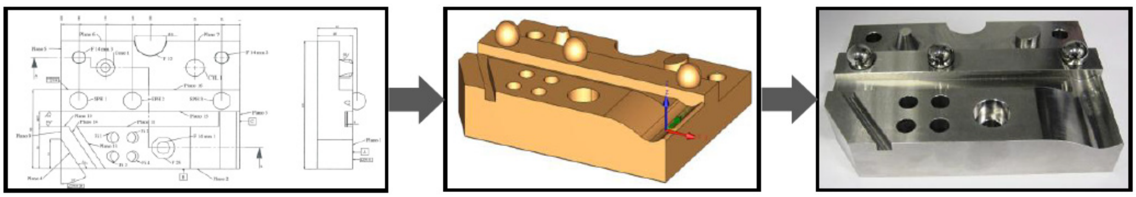

Fig. 2 - New type of artefact

With the development of this artefact, the main goal to be achieved was to develop a simple standard part, possible to measure in a CMM, who gives support to productions areas (industrial environment), and which the values obtained were traceable to a high accuracy CMM.

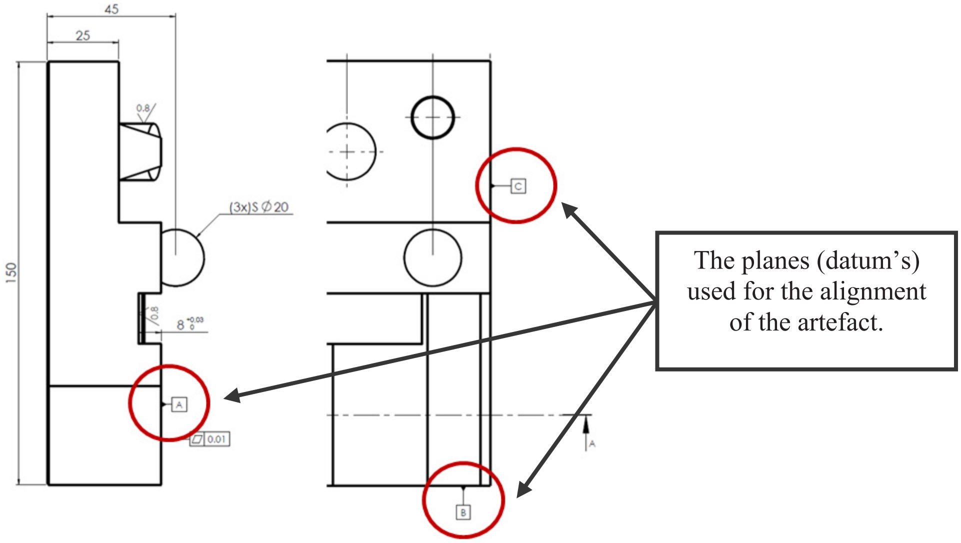

Fig. 3 – Elements for the base alignment

Then, the artefact developed was measured 3 or 5 times in each geometric element and in each measurement plane (XY plane, XZ plane and YZ plane), using to this effect a high accuracy CMM, following the method of multi-orientation (illustrated in Figure 4, Figure 5 and Figure 6) and following the measurement protocol previously defined.

The measurement protocol previously defined should indicate:

- The positioning and fixation of the artefact;
- Type of probe to be used;
- Measuring speed;
- Measuring force of probing;
- Alignment elements (datum's);
- Geometric elements to be measured;
- Number of measured points per geometric element and the distribution of the points;
- Number of cycles;
- Measurement times;
- etc.

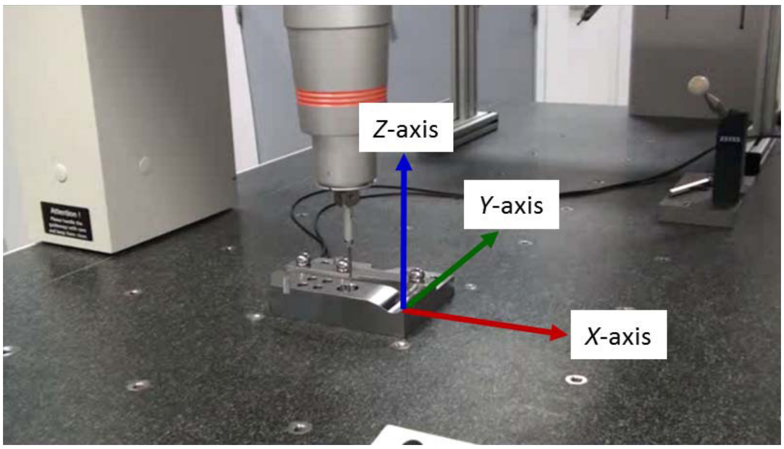

Fig. 4 – Artefact measured using the multi-orientation method (plane XY)

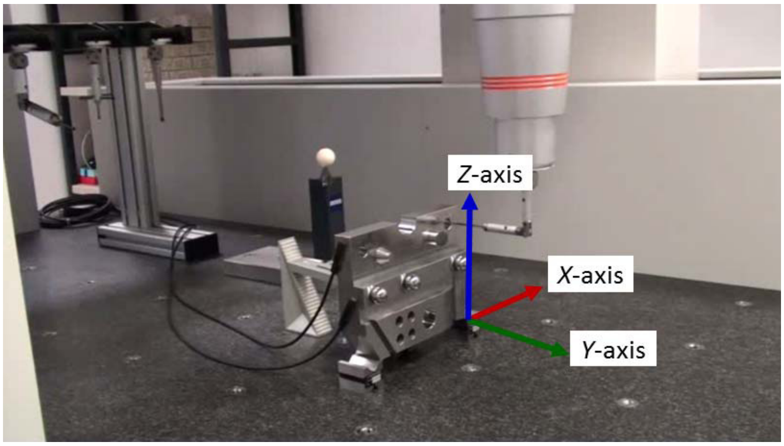

Fig. 5 – Artefact measured using the multi-orientation method (plane XZ)

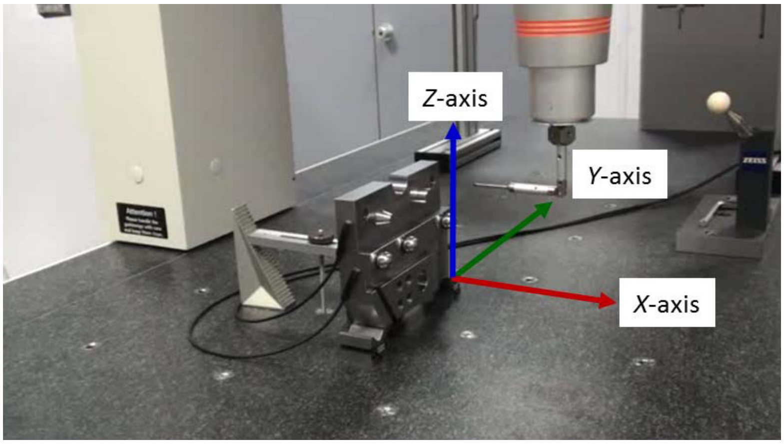

Fig. 6 – Artefact measured using the multi-orientation method (plane YZ)

The results obtained in this type of analysis must be easy to interpret, specially conclusive and intuitive for the operator to validate the CMM, and consequently also validate the results obtained in the test procedures.

2.2 The special type of artefact, objectives to be achieved

From the analysis of the deviations found, comparing with the results obtained (in the measuring process with the high accuracy CMM) and reported in the dimensional and geometrical test, we be able to validate the industry CMM and the measurement process, or not.

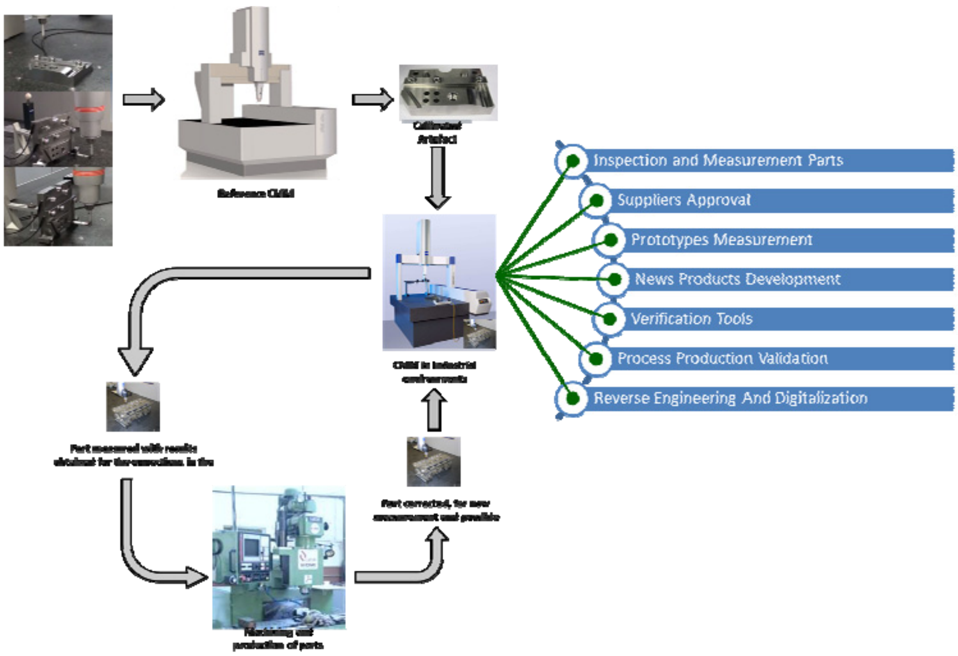

Fig. 7 – Objectives of the proposed artifact

2.3 The main factors influencing the results and the accuracy

In this study it was considered important, as a source of influence for calculating the expanded uncertainty, the following:

2.3.1 The influence of the error derived from the reference CMM and was subjected to the following treatment:

Table 1. Influence of the error derived from the reference CMM

CMM Uncertainty, type B-R
$u(x_2)$
c_2
$u_2(y)$
DF (Degrees of freedom)

$$u(x_2) = \sqrt{\frac{1}{12} \times (a_+ - a_-)^2} \tag{1}$$

$$c_2 = 1 \tag{2}$$

$$u_2(y) = u(x_2) \times c_2 = \sqrt{\frac{1}{12} \times (a_+ - a_-)^2 \times 1} \tag{3}$$

$$\mathrm{DF} = 50 \tag{4}$$

2.3.2 The influence of component reproducibility of the reference CMM and was subjected to the following treatment:

Table 2. Influence of component reproducibility of the reference CMM

Range Max-Min
Range/*U(Xi)*
U reproducibility

$$u(x_r) = \sqrt{\frac{1}{12} \times (a_+ - a_-)^2} \tag{5}$$

$$c_r = 1 \tag{6}$$

$$u_r(y) = u(x_r) \times c_r = \sqrt{\frac{1}{12} \times (a_+ - a_-)^2} \times 1 \tag{7}$$

2.3.3 The influence of dispersion of the obtained values in the measurement of the artefact was subjected to the following treatment:

Table 3. Influence of dispersion of the obtained values in the measurement of the artefact

Dispersion, type A
$u(x_1)$
c_1
$u_1(y)$
DF (Degrees of freedom)

$$u(x_1) = \sqrt{\frac{\sigma^2}{n}} \tag{8}$$

$$c_1 = 1 \tag{9}$$

$$u_1(y) = u(x_1) \times c_1 = \sqrt{\frac{\sigma^2}{n}} \times 1 \tag{10}$$

$$\mathrm{DF} = 4 \tag{11}$$

2.3.4 The influence of temperature was subjected to the following treatment:

Table 4. Influence of the temperature

Temperature, type B-R
$u(x_3)$
c_3
$u_3(y)$
DF (Degrees of freedom)

$$u(x_3) = \sqrt{\frac{1}{12} \times (a_+ - a_-)^2} \tag{12}$$

$$c_3 = \alpha \times \Delta t \tag{13}$$

$$u_3(y) = u(x_3) \times c_3 = \sqrt{\frac{1}{12} \times (a_+ - a_-)^2} \times \alpha \times \Delta t \tag{14}$$

$$\mathrm{DF} = 50 \tag{15}$$

2.4 The definition of acceptance criteria and validation of the CMM's in industry

This point is certainly one of the most critical to approach, for various reasons.

In one hand, in industrial environment we found different companies with different types of CMM's, which obviously have different characteristics.

On the other hand while some seek to comply with manufacturers specifications, always seeking for the lowest uncertainty, others seek to ensure that errors of the CMM, do not compromise the conformity of the parts produced.

As it is difficult to set an appointment serving to all types of CMM's, the recommendation presented in this paper is intended to be feasible, practical, intuitive and reliable, and represents one possible approach for evaluating the performance of the CMM's in the industry, using the new type of calibrated artefacts.

So, we determined a multiplier coefficient for evaluating the performance of the CMM in the industry, using calibrated artefacts, being considered for calculating the multiplier coefficient the expanded uncertainty certificates and the maximum permissible error of the CMM as the formula:

$$multiplication\ coefficient = \frac{u_{certificate}}{MPE_{CMM_{ref}}} \tag{16}$$

(This coefficient should be applied to all results presented in the certificates)

This formula determines a coefficient multiplicative as a result of divide the uncertainty $u_{\mathrm{certificate}}$ of each parameter to the specifications MPE_{CMMref} of the reference CMM (Figure 1). The hypothesis made this ratio remains approximately constant to change the type, brand or model of CMM.

According to the previous hypothesis, when a CMM it complies with the specifications and submit it to check test with an calibrated artefact of this type, the deviations respect to the reference values of each parameter (in absolute value) should not exceed the product of the multiplication coefficient for the specifications of the MPE_{CMMind} (Maximum Permissible Error of the industrial CMM).

$$\left| measured\ value - reference\ value \right| \le MPE_{CMM_{ind}} \times multiplication\ coefficient \tag{17}$$

Or

$$\left| measured\ value - reference\ value \right| \le AC_{CMM_{ind}} \times multiplication\ coefficient \tag{18}$$

If comply with the conditions of the formulas presented, one possible conclusion is the CMM continued inside specifications.

3. Example how to determine the multiplication coefficient and how to evaluate the performance of coordinate measuring machines in the industry

Table 5. Results from reference CMM

Measured values (mm)					Average (mm)	Expanded Uncertainty (mm)
Value 1	Value 2	Value 3	Value 4	Value 5		
14,0335	14,0334	14,0336	14,0334	14,0334	14,0335	±0,0019

Measured Value (Inside cylinder, hole-1, 14 mm) = 14,0335 mm (reference CMM value)
Expanded uncertainty (Inside cylinder, hole-1, 14 mm) = ± 0,0005 mm (reference CMM value)
MPE_{CMMref} = 0,4 + 0,001 x L (µm, with L in meters) = 0,4 + 0,001 x 0,014 = 0,4 µm = ± 0,0004 mm

$$multiplication\ coefficient = \frac{0{,}0005}{0{,}0004} = 1{,}25 \tag{19}$$

In practice, the value of multiplication coefficient of 1,25 allows to add more 25% to the value of the Maximum Permissible Error of the industrial CMM or to the Acceptance Criteria of the industrial CMM, as can be observed in the example presented in table 2.

Table 6. Results from industrial CMM

Measured values (mm)					Average (mm)	Expanded uncertainty (mm)
Value 1	Value 2	Value 3	Value 4	Value 5		
14,0361	14,0354	14,0336	14,0362	14,0353	14,0353	±0,0019

Measured Value (Inside cylinder, hole-1, 14 mm) = 14,0353 mm (industrial CMM value)
MPE_{CMMind} = 1,9 + 0,03 x L (µm, with L in meters) = ± 0,0019 mm

$$\left| measured\ value - reference\ value \right| \leq MPE_{CMM_{ind}} \times multiplication\ coefficient \tag{20}$$

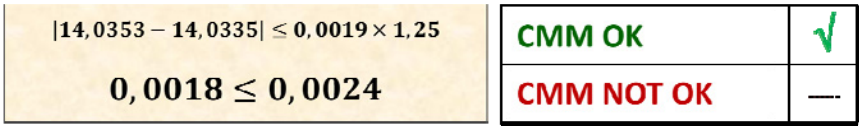

Fig. 8 – Example how to determine the multiplication coefficient and how to evaluate the performance of the CMM in the industry.

4. Conclusions

Once, the international standards refer to the need to do intermediate checks of the CMM's, to ensure the good performance of this type of equipment, leaving the development of the method and acceptance criteria for responsibility of companies.

Thus, a practical approach of this study demonstrated that there are operational and metrological adequacy using high accuracy CMM's, to do the calibration of the new type of artefacts, with several geometries, since the uncertainties obtained exhibit low values.

Throughout this study, it became clear that there is still a need to develop more types of simple and special artefacts, in some cases adequate for the type of product that each company produces and controls, in order to evaluate the metrological performance of the CMM's.

Obviously, other methods to evaluate a CMM can be developed, however this is a practical and intuitive method to check the metrological stability and conformity of a CMM.

This process allows, in one hand to control the stability and the good performance of the industrial CMM by analysis of the values obtained over time, and secondly to compare these values with the values obtained (in the same number and the same measurement protocol) in a high accuracy CMM.

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