# INTERLABORATORY COMPARISON OF ARTICULATED ARM CMMS USING VIRTUAL SPHERES PLATE GAUGE

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**Abstract:** This work presents an approach to perform interlaboratory comparison of Articulated Arm Coordinate Measuring Machines (AACMM) with Virtual Spheres Plate (VSP) gauge. This gauge has a determined number of pyramidal inserts having four conic holes each. These inserts were designed to fit virtual spheres with coordinates of the four points determined by measurement. The gauge has to be delivered to the laboratories under evaluation and the diameter and the center-to-center distances among the virtual spheres must be determined to apply normalized error analysis. The results proved suitable to evaluate the machine errors and to compare these machines.

**Keywords:** Interlaboratory comparison, Coordinate Measuring Arms, traceability.

## 1. INTRODUCTION

Interlaboratory comparison is demanded by accreditation organizations when ISO 17025 is implemented in a calibration or testing laboratory. The comparison is performed by comparing the results of a given calibration or test proposed by a laboratory (participant) against the respective measurement performed by the reference laboratory. In sections of dimensional metrology, as Caliper and Micrometer calibration, the interlaboratory comparison is well known and spread out over the industrial community. The calibration must be accomplished by using the respective National standard and gauge blocks as reference standard to perform the experimental measurements.

However, in the field of 3D coordinate metrology there is no agreement concerning the best way to perform this comparison. As Coordinate Measuring Machines (CMMs) and Articulated Arm CMMs are growing in application, the National and International entities are searching a suitable solution to this subject. The demand from automobile industries in France, Europe and America, as well in development countries around the world, is a motivation pointing to this direction. Traceability of measurements is a main topic that is under discussion at National Metrology laboratories.

A guide to accreditation of three-dimensional measures was proposed by Collége Français de Métrologie that is in agreement with the Standard ISO/IEC 17025. The guide proposed three different levels of accreditation related to the complexity of measurements carried out. The simple type was named A1 and comprises the measurement of basic geometric tolerances as flatness, circularity and straightness. The second and third types named A2 and A3 gradually enlarge the scope of measurements performed at the laboratory without requiring a new evaluation from accreditation organization. An additional category type B allows the validation of 3D measurement methods by the demanding laboratory [1].

The determination of measurement uncertainty of three-dimensional measures obtained with CMMs is considered a complicated task. There are some methods developed to estimate the uncertainty of CMM measurements but until now there is no agreement concerning the most suitable method to apply. One solution under consideration is the use one standard object that is measured by the laboratories to compare the results. This method has some disadvantages related to the costs involved, bias in methodology application and interpretation of the results [2].

A methodology related to the interlaboratory comparison of CMM measurements must evaluate the effects produced by human, technical and methodological components. A suitable method must evaluate the constructive aspects of the machine as its constructive structure, the software used to make measurements and calculations, the probe selected to determine the points and the strategy used to perform the measurements of points on the part surface [2].

An interlaboratory comparison of some methods used to verify the CMM performance was presented by literature [3]. Nine laboratories accredited by INMETRO in Brazil were compared in respect of performing measurements with CMMs. The proposed comparison protocol demanded the description of the applied methodology, the gauges used, machine probing system, laboratory temperature monitoring, measurement positions in machine work volume and method used to the uncertainty determination. The recommended methodology was the same currently applied by each laboratory but the standard ISO 10360 was considered as an alternative. The accepted gauges were gauge blocks, ring gauges, step gauges and laser systems. Probing evaluation was carried out with a gauge block or a calibrated standard sphere. The results were presented by the normalized error determined by considering the mean of laboratories uncertainties as a reference [3].

Vaissiere [4] carried out an interlaboratory comparison to analyse the measurement uncertainty of geometric deviations determined with CMMs. A part having different geometric elements was delivered to 26 laboratories and it was measured using numerically controlled CMMs. The geometric deviations of coaxiality, cylindricity, parallelism, flatness and localization were determined and compared.

The data analysis in interlaboratory comparisons is commonly performed by determining the normalized error ($E_n$). This parameter is calculated by the difference between the results of the participant laboratory ($X_1$) minus the reference laboratory ($X_{ref}$) [5], divided by the square root of the sum of squared expanded uncertainties of these two laboratories ($U_1$ and $U_{ref}$). Equation 1 shows the parameter $E_n$ formulation.

$$E_n = \frac{\left| X_1 - X_{ref} \right|}{\sqrt{U_{X1}^2 + U_{Xref}^2}} \qquad (1)$$

Another technique applied to judge the quality of a measurement result is the Youden method [6]. This method involves the graphical comparison of the data sets from the laboratories under comparison. Other methods are related to statistical hypothesis tests as correlation analysis and Student t-test, as well F-test applied with Analysis of Variance (ANOVA) and regression analysis [6, 7].

In an attempt to propose a uniform method to carry the interlaboratory comparison of CMMs and AACMMs, new approaches were presented involving the use of gauges like an optomechanical holeplate [8] and a Virtual Spheres Plate (VSP) [9, 10]. The VSP gauge has a determined number of pyramidal inserts placed over an aluminium plate, having four conic holes each. These inserts were designed to fit virtual spheres with coordinates of the four points determined by measurement and the diameter and the center-to-center distances among the virtual spheres must be determined by software calculation and compared with calibrated values of the gauge [9, 10].

This work proposes the use of the VSP gauge that was constructed and calibrated in a Cantilever CMM. An application was performed using an Articulated Arm CMM and the diameters of the virtual spheres and the distances among the centres of the virtual spheres were determined and the errors were used to evaluate the machine.

## 2. EXPERIMENTAL APPROACH

A VSP gauge having 16 pyramidal inserts, each one with four conic holes, was milled and drilled in an aluminium block. These inserts were fixed on an aluminium squared plate almost equally spaced. This gauge is depicted on references [9] and [10] and it is presented in figure 1.

The VSP gauge was calibrated with a Mitutoyo Cantilever CMM, having 400 x 500 x 400 mm work volume and standard uncertainty of 3 µm at each axis, determining the virtual spheres diameters and the center-to-center distances among spheres. These values were determined using a 3 mm ruby sphere as probe.
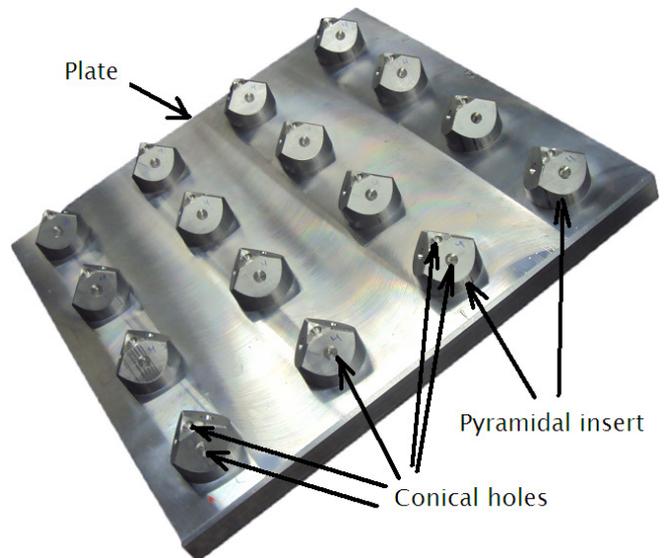


Figure 1 – Virtual Spheres Plate (VSP)

The interlaboratory comparison involves the delivery of the gauge to each laboratory to carry out the measurements. The suggested path to perform this task is showed in figure 2. The reference laboratory must verify the gauge each time it returns from participants laboratories. In this work, participant and reference is the same as only preliminary tests were performed.
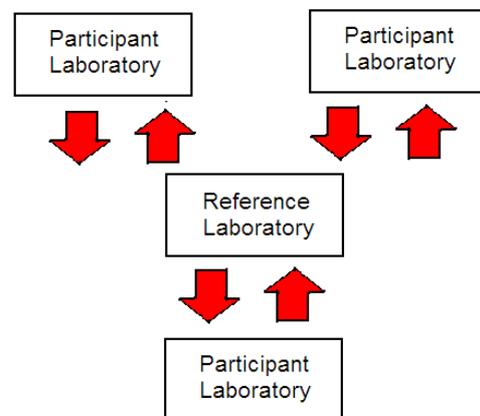


Figure 2 – Path suggested for distribution of the VSP gauge.

The methodology was applied on Romer AACMM having six degrees of freedom using a hard probe with a 6 mm diameter ruby sphere at the end, with an arm reach of 2.5 m in diameter. The software used was the GPad that was installed in the computer attached to the machine.

The gauge was positioned in three different locations of the AACMM work volume, with different lengths in relation to the origin of coordinates. Figure 3 shows the positions of the VSP at the AACMM work volume. The coordinates of the points corresponding to the holes were captured and stored using the machine measuring software. The gauge was measured twice at each position in work volume. The mean and standard deviation of the distances center-to-center of virtual spheres were determined.

A probe having diameter 3 mm (ruby sphere) was used to measure the gauge with the AACMM under comparison. Data points determined at conical holes were saved and exported in txt format file. The calculations and analysis were carried out in MatLab software to determine the errors in diameters and in the center-to-center distances.
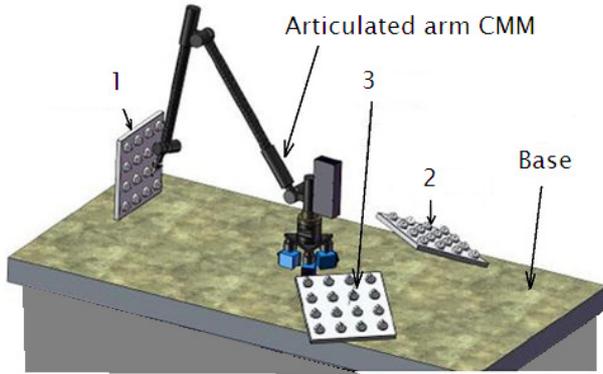


Figure 3 – Localizations of the VSP gauge in AACMM work volume.

The normalized error was considered to compare the laboratories. The reference values were considered as the calibrated values of the center-to-center distances and the diameters of the virtual spheres.

## 3. RESULTS AND DISCUSSION

The VSP was calibrated and the standard measurement uncertainty was determined as 2.5 µm to point measurements and 14.6 µm to length measurements. The diameters and the center-to-center distances were calibrated and presented in tables 1 and 2.

Table 1 – Calibrated values of virtual spheres diameter (probe sphere 3mm in diameter)

| Calibrated Virtual sphere Diameter (mm) | | | |
|---|---|---|---|
| sphere | mean | sphere | mean |
| **1** | 17.463 | **9** | 17.592 |
| **2** | 17.640 | **10** | 17.540 |
| **3** | 17.649 | **11** | 17.526 |
| **4** | 17.698 | **12** | 17.554 |
| **5** | 17.610 | **13** | 17.671 |
| **6** | 17.578 | **14** | 17.620 |
| **7** | 17.420 | **15** | 17.700 |
| **8** | 17.933 | **16** | 17.570 |

The values of the diameter of the spheres and the distances center-to-center of spheres of the VSP gauge were determined using the AACMM and the results are presented in figures 4 to 6.

Table 3 – Values of virtual spheres diameter (probe sphere diameter 3mm) measured with the AACMM

| Measured Virtual sphere Diameter (mm) | | | | | |
|---|---|---|---|---|---|
| sphere | mean | Standard deviation | sphere | mean | Standard deviation |
| **1** | 17.403 | 0.0214 | **9** | 17.624 | 0.0223 |
| **2** | 17.616 | 0.0274 | **10** | 17.517 | 0.0171 |
| **3** | 17.631 | 0.0054 | **11** | 17.526 | 0.0322 |
| **4** | 17.635 | 0.0396 | **12** | 17.553 | 0.0437 |
| **5** | 17.603 | 0.0571 | **13** | 17.684 | 0.0265 |
| **6** | 17.520 | 0.0284 | **14** | 17.580 | 0.0207 |
| **7** | 17.377 | 0.0176 | **15** | 17.656 | 0.0309 |
| **8** | 17.877 | 0.0292 | **16** | 17.584 | 0.0374 |

Table 4 – Calibrated center-to-center distances of VSP gauge, determined with the AACMM (probe sphere diameter 3mm)

| Virtual sphere | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | - | - | - | - | - | - | - | - |
| 2 | 83.070 | - | - | - | - | - | - | - |
| 3 | 165.930 | 82.860 | - | - | - | - | - | - |
| 4 | 248.969 | 165.899 | 83.039 | - | - | - | - | - |
| 5 | 83.005 | 117.354 | 185.473 | 262.372 | - | - | - | - |
| 6 | 117.346 | 82.959 | 117.366 | 185.603 | 82.883 | - | - | - |
| 7 | 185.474 | 117.196 | 82.974 | 117.413 | 165.812 | 82.929 | - | - |
| 8 | 262.312 | 185.344 | 117.250 | 82.850 | 248.812 | 165.930 | 83.001 | - |
| 9 | 165.957 | 185.478 | 234.570 | 299.073 | 82.952 | 117.203 | 185.339 | 262.237 |
| 10 | 185.693 | 165.941 | 185.436 | 234.536 | 117.497 | 82.983 | 117.123 | 185.313 |
| 11 | 234.820 | 185.555 | 165.984 | 185.505 | 185.616 | 117.475 | 83.010 | 117.306 |
| 12 | 299.336 | 234.756 | 185.695 | 166.033 | 262.475 | 185.712 | 117.560 | 83.185 |
| 13 | 248.839 | 262.328 | 299.141 | 352.059 | 165.835 | 185.469 | 234.646 | 299.225 |
| 14 | 262.247 | 248.715 | 262.211 | 299.017 | 185.353 | 165.757 | 185.337 | 234.583 |
| 15 | 298.842 | 261.981 | 248.607 | 262.124 | 234.313 | 185.189 | 165.633 | 185.383 |
| 16 | 351.888 | 298.902 | 262.179 | 248.667 | 298.995 | 234.543 | 185.371 | 165.819 |

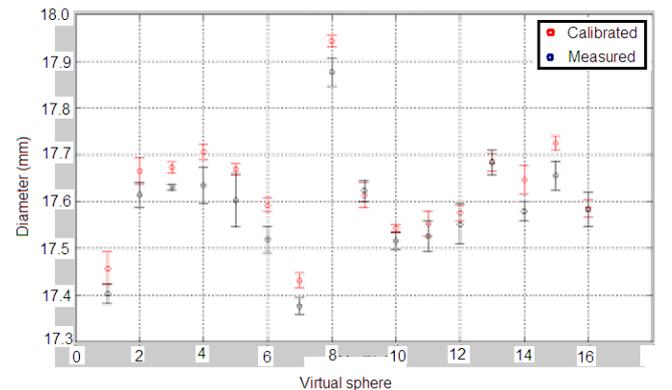| | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| 9 | - | - | - | - | - | - | - | - |
| 10 | 83.098 | - | - | - | - | - | - | - |
| 11 | 165.948 | 82.849 | - | - | - | - | - | - |
| 12 | 248.903 | 165.805 | 82.956 | - | - | - | - | - |
| 13 | 82.883 | 117.523 | 185.705 | 262.548 | - | - | - | - |
| 14 | 117.146 | 82.774 | 117.277 | 185.496 | 83.117 | - | - | - |
| 15 | 185.150 | 116.817 | 82.624 | 117.227 | 165.928 | 82.812 | - | - |
| 16 | 262.199 | 185.198 | 117.068 | 82.634 | 249.056 | 165.939 | 83.128 | - |



Figure 4 – Comparison of reference (calibrated) and participant (measured) diameters of virtual spheres.
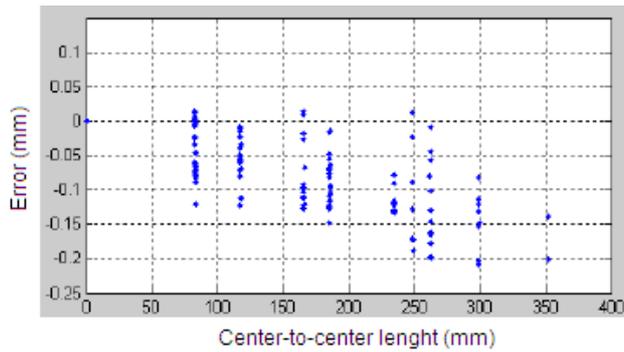
Figure 5 – Results of center-to-center distance obtained with AACMM, position 1
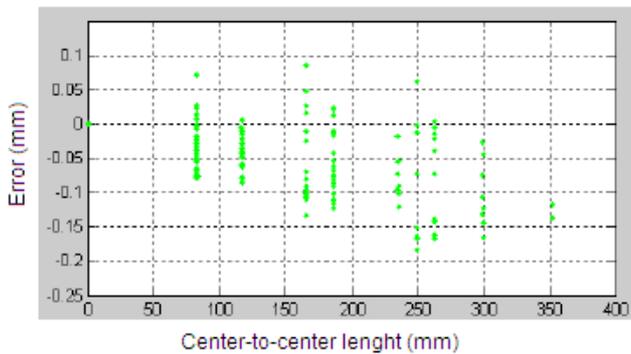


Figure 6 – Results of center-to-center length obtained with AACMM, position 2

## 4. CONCLUSION

The results proved suitable to evaluate the machine errors. New developments may address the issue of fitting different geometries to the determined point coordinates of the VSP gauge, as circles, planes, cylinder and others.

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