

A STATISTICALLY BASED PROPOSAL FOR CHECKING THE NEED OF CMM CALIBRATION

Alvaro J. Abackerli, Roxana M. M. Orrego*

Universidade Metodista de Piracicaba – UNIMEP - Piracicaba/SP - Brazil

Carlos A Camargo

Starrett Indústria e Comércio – Itú/SP - Brazil

INTRODUCTION

International standards for CMM testing guide people to have their machine verified, but there are still some doubts to define when to get it calibrated. In many cases, the calibration interval is defined on formal basis, disregarding the actual machine use.

This becomes complicated when the working conditions are not quite the specified by the CMM manufacturer. In those cases, it becomes important to have a simple but reliable test to check the machine performance.

To help users to identify the right time to have their machines calibrated, according to manufacturer's specifications, quick tests have been proposed [1,2,3] in which simple master pieces are used to generate CMM performance information. In those works, ring gauges were measured to provide information about the errors influencing the CMM performance. Figure 1 illustrates the main concepts. The underlying assumption is that a machine influenced by non-negligible errors will provide results reflecting those errors, distorting the machine's dimensional space.

If a perpendicularity error of δ does exist between directions i and j , the resulting measured diameter will show an ellipse rotated of α , Figure 1-b. If the error δ makes the angle between i and j greater than 90 degrees, the resulting ellipse will be rotated of 90 degrees counterclockwise. If a CMM error or a set of errors enlarges one CMM axis, the measured data will show an ellipse

according to Figure 1-c, resulting $h > d$. Infinite combinations of results can be obtained depending on the CMM error.

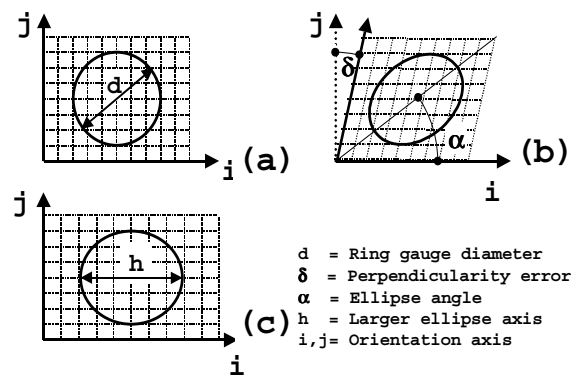


Figure 1: Concepts of CMM testing using ring gauges.

Some authors [1] claimed to identify the most important sources of machine errors observing the dimensions and angles of the generated ellipse. In those tests, no special care was taken regarding sampling strategies since they were designed to check machine tools and large CMMs subjected to errors from 20 to 50 μm magnitude. Other authors [5] apply statistical tools to improve tests reliability, providing additional information to decide about the CMM performance.

The proposal discussed here [4] aims the evaluation of medium sized CMMs influenced by smaller errors, making the issues regarding sampling strategy very important to the test effectiveness. To make it practical for users, common measurement procedures and regular dimensional

* Corresponding author

standards are used (master spheres, ring gauges, and gauge blocks). A sampling strategy and statistical data treatment are applied to improve comprehension about the CMM behavior, associating confidence levels to indicate the validity of test information. A guidance procedure to lead the user to the final decision, with little efforts on statistical processing, was implemented.

THE TEST PROCEDURE

The procedure discussed here can be defined in four steps, as following:

Step 1 – Sample size definition: it is based on the verification of homogeneity among the effective stylus ball diameters, obtained when the probe is qualified with its styli aligned to the main CMM axis, in positive and negative directions. The criterion here is to verify which probe orientation provides stylus ball diameters as repeatable as another, after several qualifications in each direction (spread of data).

The probe is qualified 5 times in each direction to get samples of probe styli ball diameter. Their variances are evaluated and compared to each other, testing for differences between pairs using Bartlett's Test [6]. If the test does not indicate statistical differences, the compared directions (styli) are said to be homogeneous. Resampling test results with 4 and 3 elements, the new variances can be evaluated by the same statistical procedure. If the variances are homogeneous with sample of 3 elements, the sample size $N = 3$ is adopted. Otherwise, the sample size is increased to 4 or 5 until having indication of homogeneity among the qualified directions (styli). If the homogeneity is not concluded the test must be repeated under better experimental conditions.

Step 2 – Identification of comparable results: similar comparisons are made using the averages obtained from probe qualifications in each direction, in order to identify which results taken in the planes XY, XZ and YZ can be compared. The criterion here is to use single-factor Analysis of Variance [6] to verify which set of probe orientations can be said homogeneous, using the defined sample size N at the chosen confidence level. If the homogeneity among all orientations (styli) cannot be accepted by the statistical test, it is necessary to apply the Tukey Test [6] to identify the differences.

Step 3 – Working volume mapping: here, a gauge block and two ring gauges are positioned at the volume areas defined in Figure 2, and measured using regular measuring procedures.

A gauge block of 100 mm is positioned and measured in each area, as shown in Figure 2, by the center points of its calibrated faces. One of the ring gauges is chosen with a 100 mm diameter and the other one with a diameter between 1/2 and 1/3 of the shortest axis of the machine. They are measured N times in each orientation, according the planes XY, XZ and YZ, within each area.

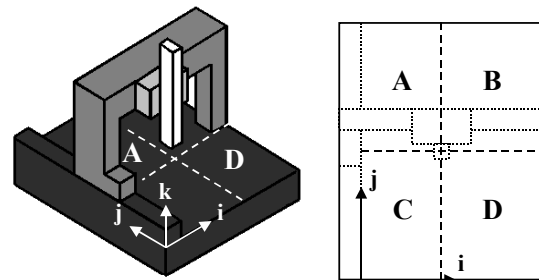


Figure 2: CMM areas for volume mapping

The distances G1-G2, G3-G4, G5-G6 and G7-G8 of the ring gauges are measured, Figure 3, besides their diameters and volume positions. The average results are also compared to each other by Analysis of

Variance [6] and possible influences on the machine performance are identified as already described.

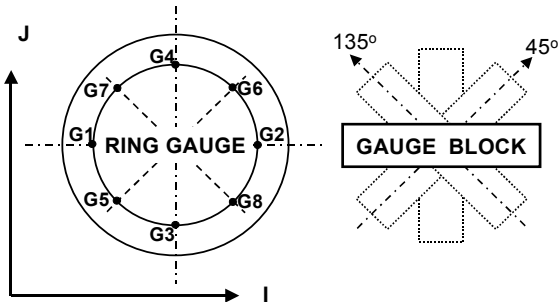


Figure 3: Ring gauge diagonals and gauge block alignments

Step 4 – Performance diagnostic: a comparative analysis identifies the most likely influences on the machine behavior, under the specific test conditions. The criterion is to use redundant information and statistical analysis to conclude about the machine performance against its specification and the evaluated test uncertainty [7]. Similar behaviors obtained from different tests give indication of identifiable CMM errors. The more the agreement of information, the strongest is the indication of presence of machine errors. A similar comparison is made using the diagonals information, G5-G6 and G7-G8, and the gauge block length, obtained at 45 and 135 degrees, to provide indication of possible perpendicularity errors.

If no conclusive indication is obtained, the machine performance is taken as appropriate and no further action is necessary. Otherwise, the appropriate action may be defined from the results. The timely repetition of the complete procedure gives indication of the CMM reproducibility; from which one can evaluate the right time to have the machine calibrated according the manufacturer's specification.

It is important to emphasize that this test is

proposed only to indicate the machine performance under specific test conditions and the eventual need of a machine calibration. Therefore, it is also important to note that any conclusion should be made against the CMM expanded uncertainty evaluated according the ISO GUM [7] and considering influences of the environmental conditions, about the specified limits of the machine and the declared uncertainty of each test standard. Its most important aspect is the confidence on statistical validation to accept test results. This allows the optimization of the number of necessary measurements, depending on the CMM working conditions, besides adding confidence limits on the performance statement. Finally, it is worth to mention that the final diagnosis from the proposed test is user dependent, making some experience on dimensional measurements a necessary condition to the procedure application.

EXPERIMENTAL TESTS AND RESULTS

The evaluated machine was started up to get operational equilibrium together with auxiliary devices, master standards and fixtures. Probe configuration, measuring speed, probe force and approach distance were adjusted and/or selected as close as possible to their usual working conditions.

A 20 mm long stylus with a 3 mm ball diameter was selected. The approach distance was set to help the elimination of vibration, due to the machine movements. Further consideration on parameters can be found in literature [8]. Master standards with calibration uncertainty small than 20% of the machine specification were also selected to perform the discussed tests.

The probe qualification was performed 5 times in each direction and tested applying Bartlett's test [6] on samples of 5, 4 and 3 elements, resulting in a B_C of 3.94, 3.53 and 2.17, respectively. Taking a confidence level

α of 5%, a critical value of 9.45 was found, indicating that all tested sample sizes satisfy the homogeneity criterion, and giving the smallest sample size ($N = 3$) as sample size for the analysis of the probe orientations averages and for the gauges tests in the different volume areas.

With the defined sample size the comparable test results were chosen after applying analysis of variance [6]. Using the same confidence level of 5%, a critical value of 3.45 was selected, indicating non-homogeneity of averages on the tested probe orientations. Tukey's test was applied to identify the comparable results, reaching non-comparability between the data collected in the XY and XZ planes.

To get the final performance diagnostic test results have been compared using the discussed analysis of variance, providing statistical evidences of CMM errors. Tests show statistical confidence of ring gauge ovalization on the XY plane, but not in the other ones, indicating a probable perpendicularity error between axis X and Y. The measurements initially indicated the probable existence of displacement errors, which were not confirmed later by the experimental uncertainty [7]. Further analysis indicates the experimental standard deviation as the largest portion of the combined uncertainty, showing the need of better experimental conditions for a better CMM diagnostic.

FINAL REMARKS.

The discussed test provides a statistically oriented selection of sample size and some useful information about CMM performance, making the decision to calibrate the machine easier to the regular user. It also emphasizes the dependence of diagnostic on the actual experimental conditions. It is important to mention that further analysis on test results can be made to investigate other aspects of the machine behavior, even though the

detailed identification of each error source is not the objective of the discussed test procedure.

Keywords: CMM testing, performance evaluation, kinematic errors, statistical methods.

Acknowledgments: the authors would like to thank the financial support received from the *Starrett Indústria e Comércio, Ltda*, UNIMEP and FAPESP for the development of this work.

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