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A SIMPLE SOLUTION TO INTERIM CHECK OF COORDINATE MEASURING MACHINES

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Abstract: This paper describes the development of a simple solution to the problem of performing interim checks in coordinate measuring machines (CMM). The design constrains have been chosen in such a way that the resulting product can be used in small and medium sized industries of Brazil and other emergent economies.
Keywords: Coordinate Measuring Machines, Interim Check, Hole-Plate.

1. INTRODUCTION

The behavior of a coordinate measuring machine (CMM) may change during the interval between verifications. Undocumented changes in the state of the CMM may compromise the validity of all future measurement[1]. To avoid this uncomfortable situation, the implementation of interim checks, which are much faster and simpler than complete verifications, is strongly recommended[2].

A large variety of methods have been proposed over the past decades. According to the PTB[1], the ideal method for interim check[2] should combine[3]:

- Traceability;
- accuracy;
- compatibility between the calibration;
- acceptance test and interim checks results;
- possibility to perform calibration;
- acceptance test and interim checks with the same hardware and software;
- compatibility with existing standards;
- and possibility to be performed by the user.

These demands can be better met by the use of reference objects. The most commonly used artifacts are ball bars, ball and hole plates and the machine checking gauge[2]. Tetrahedrons and ball cube are three dimensional solutions created with the intent to save testing time. One-dimensional artifacts are usually cheaper and easy to transport. However, a comparison made between the ball cube method, a 4 holes plate and a 2 balls bar shows that while the 3D artifact measures 18 probing elements in 1 set-up position, the 2D artifact measures 19 probing elements in 4 positions and the 1D artifact measures 32 probing elements in 10 positions[4]. On the other hand 3D, artifacts are rather hard to handle and transport.

Even though the interim check concept is widely known, it is seldom applied in Brazilian industries. A research made between 1997 and 1999 within the CMM users in Brazil, shows that 9% of the CMM are verified daily, 21% weekly and 12% monthly[5]. Most of these CMM are in service in big global companies and their main suppliers. On the other hand, most small and medium companies do not perceive the need to invest in frequent performance tests of their CMM. These companies use to be dependent on external metrology services (*i.e.* CMM manufacturer or calibration laboratory) to check the CMM when any incident occurs.

This paper describes the development of an artifact and application software to be used in the interim check of industrial grade, intermediate accuracy CMM. The design constrains have been chosen in such a way that the resulting product can be purchased by and effectively applied in small and medium sized industries of Brazil and other emergent economies.

2. DESCRIPTION OF THE SOLUTION

2.1. The Artifact

To encourage its frequent use and be in the accordance with the ISO 10360-2 standard, an artifact has been designed to meet the following requirements:

a. Easy to calibrate;
b. Capability to track the main parametric errors of the CMM;
c. Capability to be scaled proportional to CMM application volume, for a better volumetric diagnosis;
d. Lightweight enough to be easy to handle, store and transport;
e. Robust enough to withstand light impacts without generating doubts on the integrity of the artifact and validity of its calibration;
f. No heavy and/or complicated supports;
g. No complicated assembly and disassembly operations;
h. Low cost;
i. Little operator training required.

To fulfill the above mentioned requirements, a 2D artifact with four probing elements was chosen. Even though

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more information could be achieved with a 3D artifact, the cost of such an artifact would be higher and its transportability, hardness and stiffness would be lower[6]. The plate concept is suited for machines with a measurement range not bigger than 1200 mm[7]. Besides it can be calibrated using a CMM with uncorrected geometrical errors by means of reversal techniques, requiring only the use of substitution techniques to reduce displacement errors. It has also the capacity to detect variation in geometric errors, such as scale, squareness, roll, pitch and yaw.

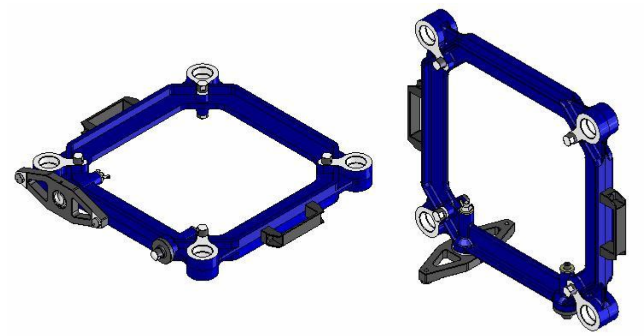

Fig. 1: Proposed artifact placed in horizontal and vertical position (400 x 400 mm).

One of the problems identified in interim checking is the time lost during the artifact set up. In order to solve this problem, a lightweight support has been developed in such a way that the assembly operations required to change the artifact orientation are minimized. Fig. 1 presents the designed artifact on its supports in the horizontal and vertical operating positions.

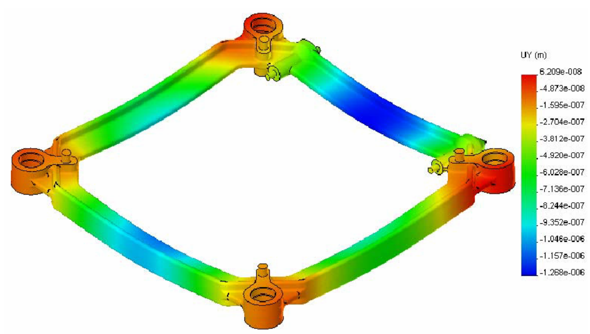

Fig. 2: FEM analysis of vertical displacements of the plate placed in horizontal position and supported in four points (500 x 500 mm - loaded by self weight).

There are a couple of requirements that need be considered when selecting the material of a standard object. Dimensional stability, mechanical robustness and hardness of the contact surface are properties that must be found in the proposed materials. Materials like zerodur, iron, ceramic, titanium, aluminum and carbon fiber are commonly used in calibration and verification artifacts. However, most of them are either expensive, hard to work with or heavy. The selected material is a high-stability aluminum alloy. To save costs in machining process, the artifact is sand-cast in aluminum. It was chosen instead of cast iron because of its lower density, achieving a total mass lower than 6 kg for an artifact size of 500 x 500 mm, and because its rapid temperature stabilization. The ISO 10360-2 recommends that the interim artifact material should have the same coefficient of thermal expansion that the typical work piece measured with the CMM[2]. However this recommendation cannot be completely accomplished, since iron and plastic parts are also easily found in the industry. Nevertheless, the thermal effects can be mathematically compensated if temperature records are appropriately taken during measurements.

Because of the need to achieve a low mass, a four-linkage geometry was used. Using the finite element method (FEM), the plate design has been optimized, minimizing the displacements of the reference elements by the artifact's own weight. Thus, when the plate is placed in horizontal position, i.e. lying flat on the CMM table, the reference holes remain with their axis perpendicular to the table and the change of distances between holes are also in the sub-micrometer range, lower than 0.1 µm (see Fig. 2). When placed in vertical position, the symmetry of the artifact assures also limited deformation. Rigid body displacements predominate over geometry changes due to self weight (see Fig. 3), so the change of distances between holes remains also in the sub-micrometer range.

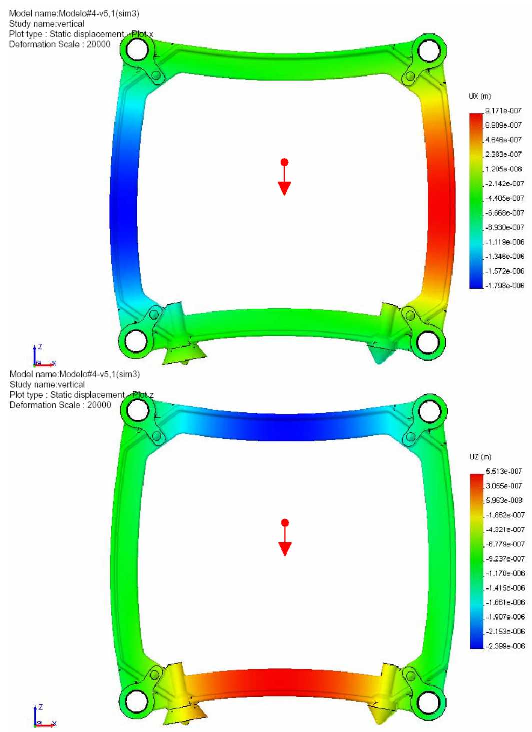

Fig. 3: FEM analysis of horizontal and vertical displacements of the plate placed in vertical position and supported in three points (500 x 500 mm - loaded by self weight).

2.2. *The Interim Check Procedure*

The set up of the artifact is the same used by the hole and sphere plate when calibrating CMM[8]. It was chosen because of the facility to be understood and executed by the CMM operator. The interim procedure will differ from the one used for calibration in the number of set ups for each event (three instead off six), as well as the number of probing elements (only four). Fig. 4 shows the three positions of the artifact on the CMM table.

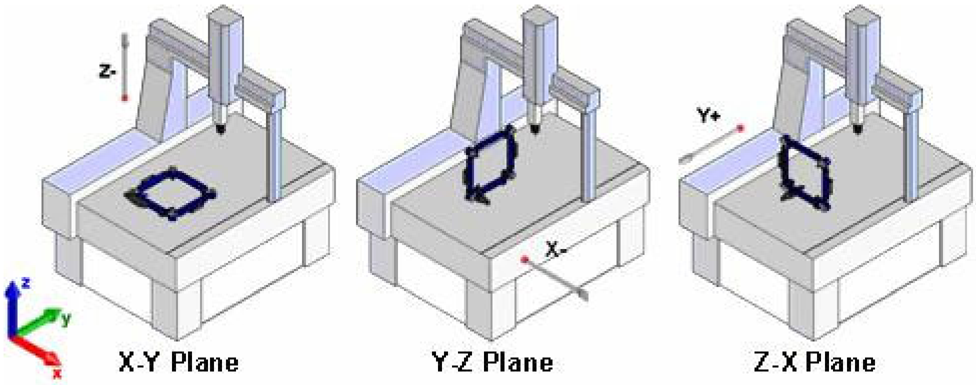

Fig. 4: The three positions of the artifact in the global coordinate system.

Despite a four-hole plate is sensitive to changes in all 18 geometric errors, only six parameters are explicitly evaluated. Three of those tracking parameters are the deviation in each axis, dx, dy and dz. The other three tracking parameters are the squareness errors in the xy, yz and zx planes. The six parameters were chosen because they are strongly influenced by position and squareness errors, which are those more susceptible to change due collisions and other incidents. It should be understood that the artifact geometry does not allow separating rotational from squareness errors, but this is not critic since the intent of interim check is not to provide information for diagnosis. The estimates of these tracking parameters can be obtained in two different ways, with and without temperature compensation. Thus, it will be possible obtaining also a description of the effect of environmental temperature variation on the CMM.

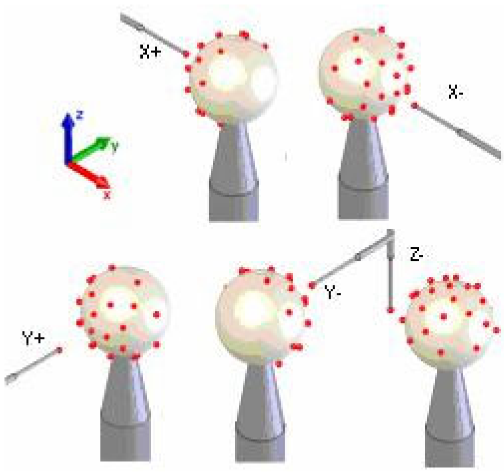

Fig. 5: Probing test.

An effective interim test checks the total CMM measurement system including sub system components which are used in normal operations of the CMM[1]. This includes, among others, the probing system, which is checked according to the ISO 10360-5. A test sphere is measured with five styli (Fig. 5), obtaining a sample of 25 points with each styli[9]. The probing system tracking parameters are form-related, size-related and location-related errors[9].

3. RESULTS

3.1 Manufacturing

The artifact went through two manufacturing processes: casting and machining. The designed geometry presented no significant problem during casting. The material filled up the mold very well. No defects were observed in the machined surface.

The results obtained in machining where also positive. Since cylinder holes are used as probing elements, a plane for normal reference is needed. It was achieved less than 10 µm for flatness and less the 5 µm for the hole circularity. The contribution of form error in the measurement of the hole center is minimized by measuring and calibrating the artifact using the same probing points. Fig. 6 shows the developed artifact.

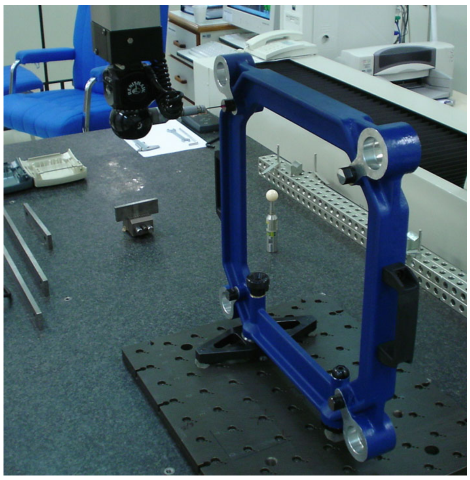

Fig. 6: Alpha prototype (400 x 400 mm).

3.2 Calibration of the artifact

The procedure adopted for the artifact calibration is the same as the used for ball or hole plates following DKD guideline. The procedure consists of two steps:

In the **first step,** the artifact is measured in four different positions. One with the same coordinate orientation of the CMM and the other three positions rotated about each of the CMM axis. This allows the elimination of straightness, yaw and squareness errors.

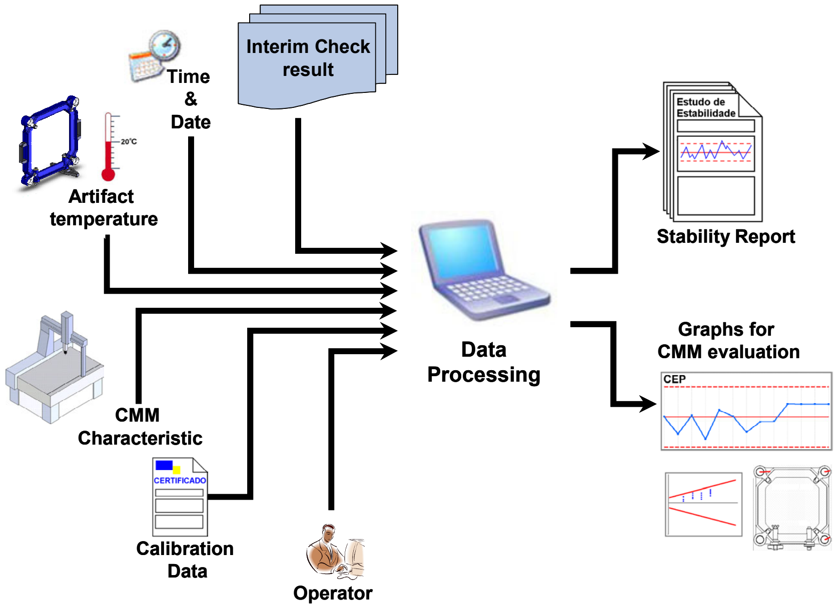

Fig. 7: Inputs and outputs of the software.

This step consists in the application of self-calibration method, where only systematic errors can be compensated. The systematic error to be compensated should be significantly greater than the random errors, i.e. the CMM must be highly repeatable[6];

The **second step** is the direct comparison between the length measured for two artifact holes in the x direction and a standard of size positioned parallel to the vector defined by the two holes. The same procedure is performed with two holes in y axis direction. This allows the correction of scale errors. At this step the traceability to the unit meter is established.

The uncertainty achieved is expressed by the following equation:

$$U_{95\%} = 0.5\mu m + 1.2 \cdot 10^{-6} \cdot L \qquad (3.1)$$

Where:

L [m] = distance between holes;

$U_{95\%}$ [μm] = uncertainty of arbitrary distances between holes, with coverage factor k=2.

3.3 Application Software

The verification results are evaluated by means of an off-line application software. The **inputs** to the software are: the calibrated distances between holes; the results of the periodical verifications; the average temperature of the artifact during each check event; and the probing system checking result.

It is accepted that for a measurement process to give meaningful result, it has to be in a state of statistical control[10]. Given that the procedure is aimed to check for instabilities of the CMM, the **outputs** of the software are statistical process control charts. The charts are plotted using the six tracking parameters from the artifact measurements, three from probing system test and the temperature. Charts for individual values where chosen to save time on repetitions, and considering that CMM short term stability is very good. A diagram of the inputs and the outputs can be seen on Fig. 7.

The time between successive check events (e.g. daily, weekly) can be defined by the user, considering the stability of the CMM-environment condition and measuring performance required[2]. If there is any suspition of change in the CMM geometry (e.g. after getting atypical results or after a collision), a complete three-position interim check can be performed, providing concise information on the condition of the CMM with a little extra effort.

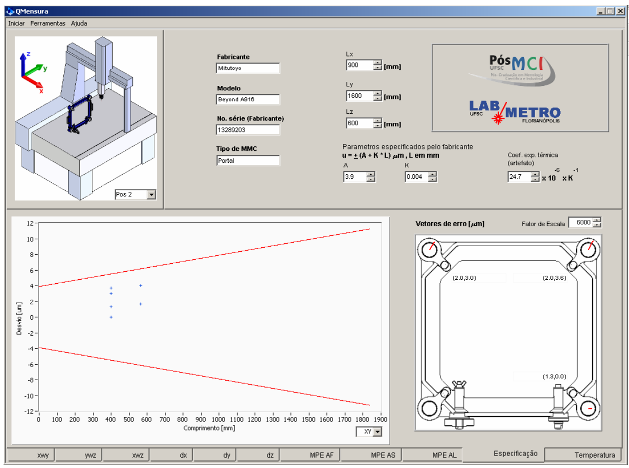

Fig. 8: Main screen of the software.

The software user interface was designed to be self explanatory making it easy to operate and interpret the results. The main screen of the software is presented in Fig. 8.

3.4 *First Application*

So far, the proposed solution was only applied in laboratorial environment. The chart in Fig. 9 shows the variation of the squareness of the x (carriage) and z (arm) axis of the evaluated bridge type, industrial accuracy grade CMM. The value obtained for the range between control limits was 7 µm/m, which is lower than the specified value for the uncertainty of the CMM. Thus, a change on the CMM behavior can be observed before its measurements become greater than the specified for uncertainty.

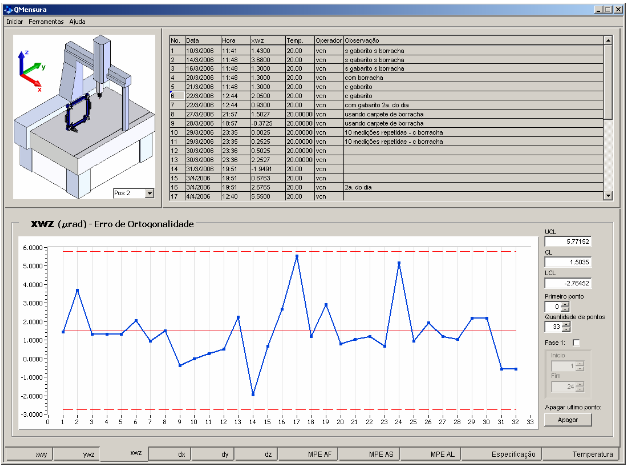

Fig. 9: Evaluation of squareness between X-Z (xwz).

One of the most important requirements of an interim check method is testing time. The measurement of the artifact in the three proposed position can be done in less than 10 minutes when the CMM table is marked and the probing test is done in less than 7 minutes. To save time, the authors recommend the measurement of only one position at once. This could reduce the checking time to less than five minutes a day.

4. CONCLUSION

The main intent of this work is to promote the practice of interim checks in medium and small Brazilian industries. A research made by the authors on the literature and on the solutions available in the market concludes that the plate concept (2D artifact) is the best solution. Yet, most of the plates found in the market have its focus in calibration and in acceptance verifications having characteristics that make them less appropriate for interim check. Based on problems such as testing time, price and facility to handle and transport, the design requirements were established.

So far the achieved results are satisfactory. The artifact can be calibrated with a relatively simple procedure using reversal technique; it can detect changes of any geometric error (limited by the number of probing elements); it is light weight, and because of its bi-dimensional shape it is easy to store and transport; the developed support is not complex to use resulting in low set up time; and the prototype costs make it affordable for small and medium Brazilian companies. However some requirements still have to be proved such as long term stability, capability to withstand impacts without generating doubts in validity of calibration and capability to be scaled up to 500 x 500 mm, even though it is possible according FEM analysis.

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