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# LOCAL CALIBRATION METHOD USED FOR INCREASING MEASUREMENT ACCURACY OF POLYARTICULATE ARM SYSTEMS

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***Abstract:*** Polyarticulate arm systems have become very common in the machinery industry and especially in the automotive industry. This is due to the dramatic drop of the cost for such equipment, which has been the case in recent years. Another reason for the extensive use of the polyarticulate arm in the industry is the simplification of the measuring process and, in parallel, the development of the associated software for this equipment. However, the polyarticulate arm also has an important drawback: low precision. Initially, these measurement systems were designed to perform complex 3D measurements with the usual ±0.2 mm precision. This low precision is due to the chaining of the kinematic rotation couplers in the polyarticulate arm structure, which are often in the number of 5 and 7 pieces. Obviously, a complete kinematic chain calibration can be performed. But this does not solve the problem of increasing accuracy of measurement, but only restoring the system to the initial stage by eliminating the influence of mechanical wear in the kinematic couplets. This paper proposes a method (measurement technique) that increases measurement accuracy of the polyarticulate arm by performing a temporary and local calibration to be performed at the beginning of each set of measurements. This method does not depend on the state of the system (new or used), but depends on the type of measurement to be performed.

***Key words:*** polyarticulate arm system, 3D measurement, accuracy, calibration.

## 1. INTRODUCTION

Polyarticulate arm (PA) is a powerful, modern and versatile measuring system. It is mainly used in mold making industry and in the automotive industry. If for the automotive industry the measuring accuracy of the PA is relatively acceptable, when measuring complex 3D parts such as the bodywork of the automobile, the use of PA in the mold making industry is problematic because the mold manufacturing precision is higher than that the PA system of measure [1, 2, 3].

Sometimes, even for the automotive field, PA accuracy is no longer sufficient. In the mold industry, basic measurements are made only on CMM systems (computer measuring machines). If we could somehow increase the measurement accuracy of PA, then we would get the following benefits [4, 5, 6, 7]:

- First, the price of a PA system is at least 10 times lower than a CMM system.
- The second most important thing is the duration of the measurement process and the effort made to perform the measurement. For example, measuring a piece on PA system may take 10 minutes, and the same piece measured on a CMM system takes at least 2 or 3 hours.
- PA does not require skilled labor at the level of expertise of the CMM system.

Clearly, there are also shortcomings of the PA system over the CMM: the main drawback is the measurement accuracy that can be about 10 to 100 times better on CMM.

In our laboratory we have proposed to use the PA system to measure molds. If we are able to measure nearly 10-times better precision than the one guaranteed by the polyarticulate arm manufacturer, then the method will prove effective [8, 9, 10]. This paper describes how we solved this problem and the results obtained in the laboratory.

## 2. MODIFICATION AND ENDOWMENT OF PA SYSTEM

In order to measure typical pieces from the mold assembly, we had to equip PA system with modified probes. The PA system used in the laboratory is Faro® Edge type (Figure 1).

To expend the capabilities of the PA system, we developed several port-probe cones. The drawing of these cones is shown in Figure 2. Two cones manufactured by us and one original Faro® are shown in Figure 3.

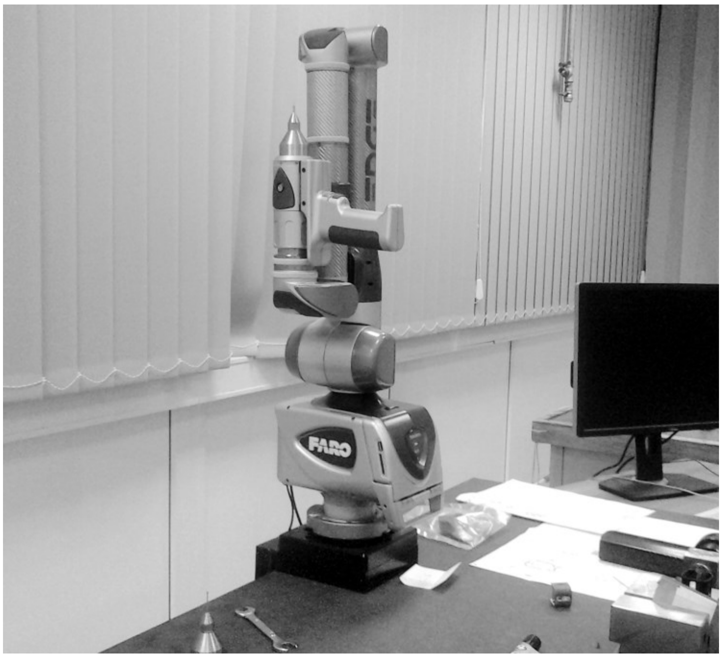


Fig. 1.  Faro® Edge seven axis polyarticulated arm

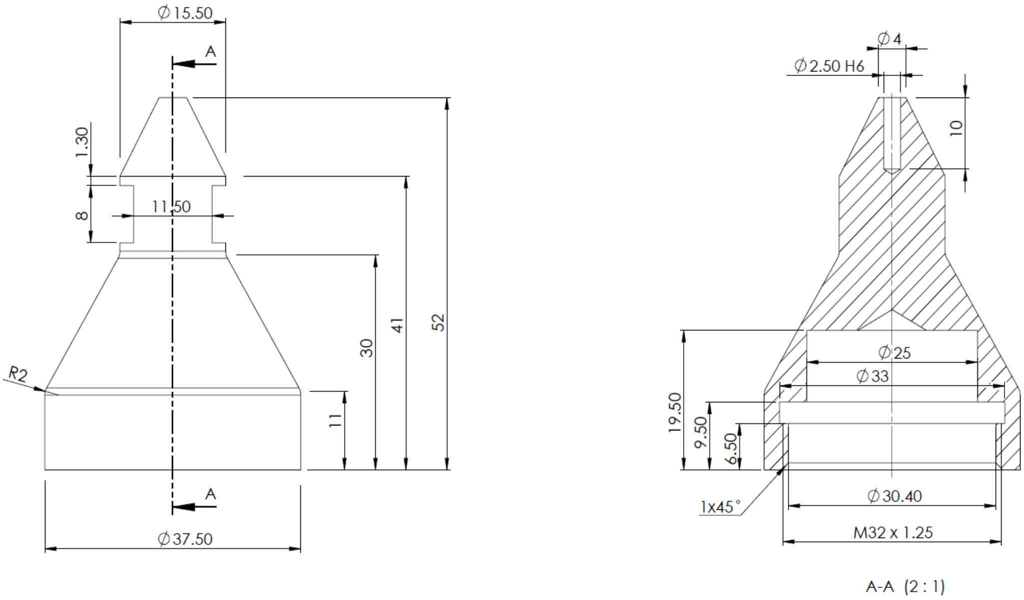


Fig. 2.  Drawings of Faro® Edge cones

Fig. 3.  Additional Faro® Edge cones for expanding measurement capabilities

In principle, the diameter of the probe spheres is 3 and 6 mm. If we can increase measurement accuracy, then we also need smaller diameters, eg. 1 mm, 1.5 mm and 2 mm. For use, the manufactured cones are assembled with touch probes as in the drawing shown in Figure 4. The assembly of projected parts seen in Figure 4, after mechanical machining shows as in Figure 5.

The technological issue is to achieve the assembly precision as in Figure 4. To solve the required precision, we have used comercial precision-worked ball bearings.

But even for ready-made ball bearings, there is the problem of achieving a 0.6 mm bore in the center of the ball. The easiest thing to do was to perform the borehole through the electro-erosion process with a filiform electrode.

The electro-erosion machine with which we have made precision machining is shown in Figure 6. We used this tool machine for other educational purposes as well [11, 12, 13. 14].

Unfortunately, this is not a CNC machine, so we had to design a centering device that precisely places the filiform electrode against the center of the ball.

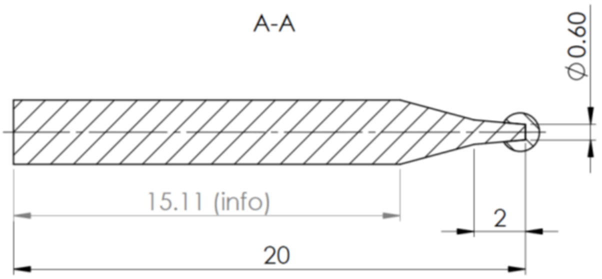


Fig. 4. The touch probe assembly drawing

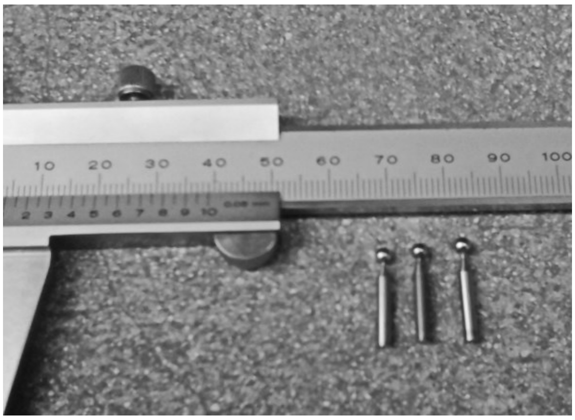


Fig. 5. Touch probe samples after mechanical machining

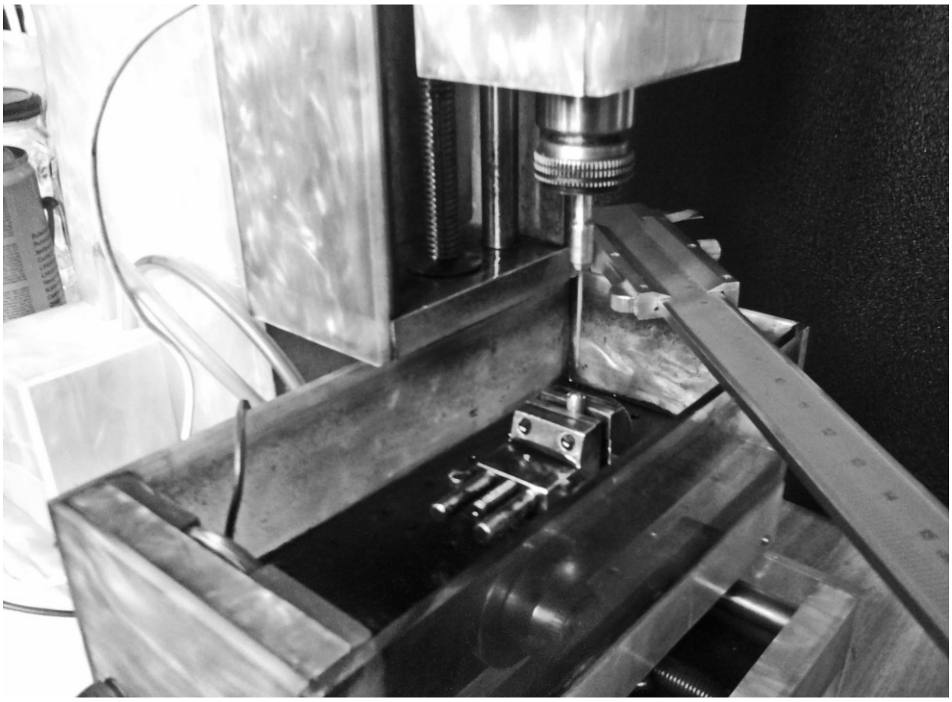


Fig. 6. The electro-erosion machine with a filiform electrode

Figure 7 shows general view of the the centering device, and Figure 8 shows the device operating diagram. The centering device consists of:

1 - machine tool table;
2 - fastening-centering sleeve;
3 - support bush;
4 - the workpiece (the ball to be machined);
5 - guide sleeve;
6 - filiform electrode;
7 - machine tool head.

The electrode is guided by the guide sleeve. The guide sleeve is made of electrical insulating material, preferably from sapphire, ruby, ceramics or glass. The entire centering device moves freely onto the machine tool table, positioning itself along the electrode axis. After the positioning process, the centering device is blocked onto machine tool table.

The whole assembly (centering device plus workpiece) is placed in the machine's electroerosion vat, submerged in dielectric fluid.

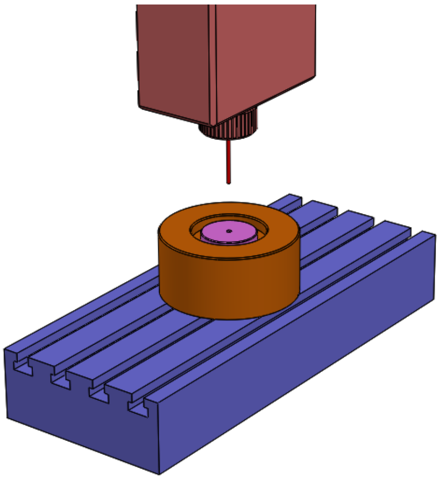


Fig. 7. General view of the centering device

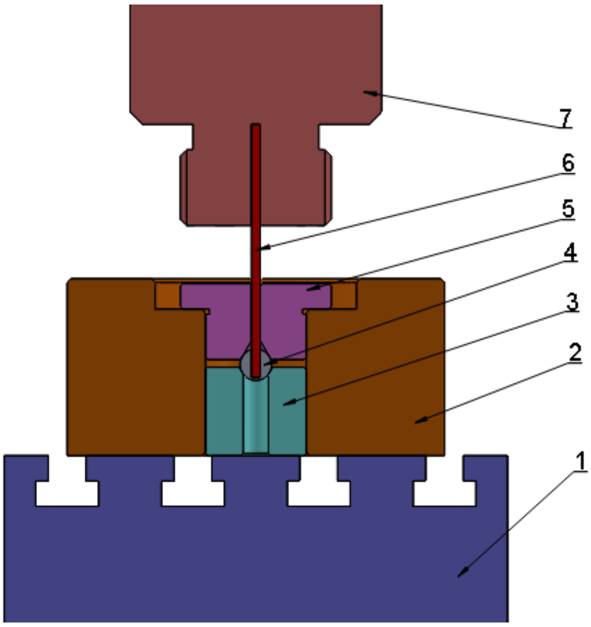


Fig. 8. Device operating diagram

The advantages of this centering device design are:
- very tough balls of good electrical material can be processed, specific to the electro-erosion process;
- it is possible to achieve precise positioning of the electrode in relation to the part: the positioning is adjustable. The precision of machining also depends on the precision of the fabrication of the device;
- changing the electrode can be done easily, keeping the concentricity adjustment;
- the construction of the centering device is relatively simple.

The drawbacks of this centering device are:
- electrode centering is relatively difficult;
- the production capacity of the electro-erosion process is low.

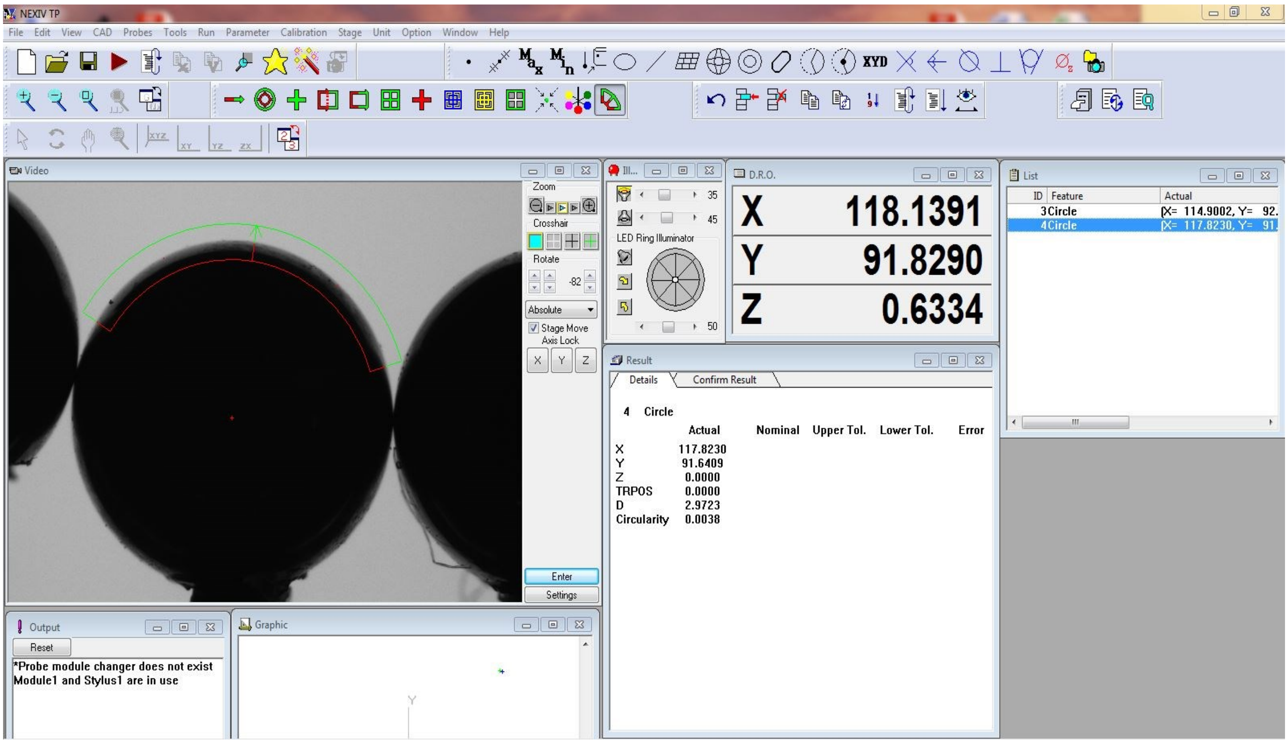
Once the touch probe manufacturing process has been completed, we have moved on to precisely measuring these mechanical assemblies. For this, we used a Nikon® *iNEXIV VMA-2520* type microscope. This microscope is multi-sensor measuring system, with fast, fully automatic and high accuracy features [15]. The iNEXIV is suited for a wide variety of industrial measuring, inspection and quality control applications, designed to measure 3D workpieces. Furthermore, this microscope is touch probe ready, integrates the latest imaging processing software, and in addition integrates 10x optical zoom system and Laser Auto Focus. This microscope is presented in Figure 9, and the manufactured parts on measurement process are shown in Figure 10.

Fig. 9. The microscope Nikon® iNEXIV VMA-2520 type used for measurements

Fig. 10. The manufactured touch probes

This precision optical measuring system also contains associated software NEXiV TP that is shown in Figure 11.

Although we made the measurements for touch probes and cones with high precision Nikon® *iNEXIV VMA-2520*, the general assembly can also be inspected with the Inspectis® C12x system. This system is shown in Figure 12.



| X | 118.1391 |
|---|---|
| Y | 91.8290 |
| Z | 0.6334 |

| ID | Feature | Actual |
|---|---|---|
| 3 | Circle | (X= 114.9002, Y= 92. |
| 4 | Circle | (X= 117.8230, Y= 91. |

4 Circle

| | Actual | Nominal | Upper Tol. | Lower Tol. | Error |
|---|---|---|---|---|---|
| X | 117.8230 | | | | |
| Y | 91.6409 | | | | |
| Z | 0.0000 | | | | |
| TRPOS | 0.0000 | | | | |
| D | 2.9723 | | | | |
| Circularity | 0.0038 | | | | |

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*Probe module changer does not exist
Module1 and Stylus1 are in use
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Fig. 11. NEXiV TP software used in the measuring process

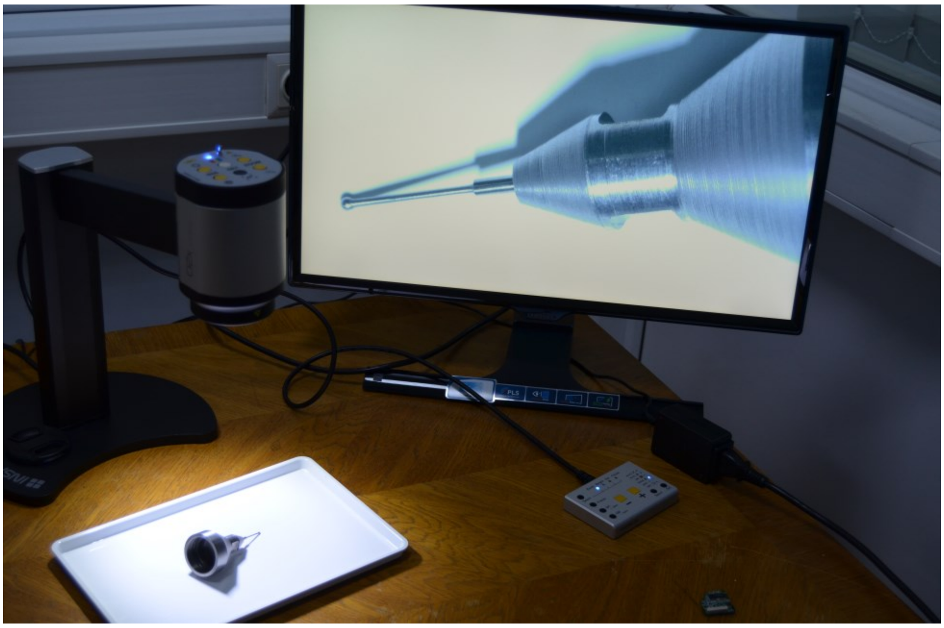

Fig. 12. Inspectis® C12x system used in the measuring process

Inspectis® C12x is an integrated high definition video inspection and measurement system. The system incorporate high resolution lens system with 12x optical zoom, autofocus, on-board camera and lens controls, integrated pure white LED illumination, and 240 mm working distance. We considered that this system of measurement is sufficient for the final inspection of the assembly we have made [16].

As a general rule, we considered that we need to produce cones and touch probes in class 5, or preferably in class 4 precision (IT5 or IT4). This was not possible in our laboratory conditions, but we finally managed to use the following technique: we produced 10 assemblies, of which we finally selected only 2 – using the measurement systems listed above –, which were the best in terms of precision.

## 3. CALIBRE FOR MAKING 3D MEASUREMENTS

To increase the measurement accuracy of the PA system, we designed a calibration part (calibre) to be measured on the PA system before starting the measurements for the actual piece [17, 18, 19, 20. 21, 22, 23].

This caliber is shown in Figure 13 – general view. The design drawing and the important dimensions of the caliber is shown in Figure 14 (dimensions are in mm).

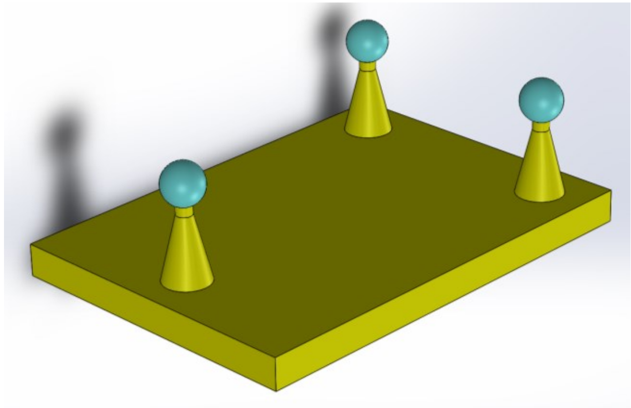

Fig. 13. The calibre – general view

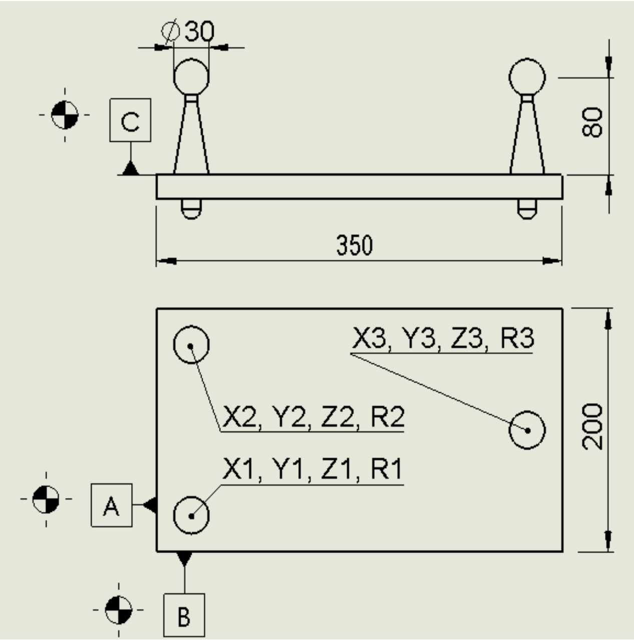

Fig. 14. The calibre – dimensions

The procedures given in this work will be helpful in identifying PA system uncertainty components for specific measurement tasks, and that the user will be able to reduce errors by removing contributing elements such as long probe extensions and styli or sensors erorr, then retesting the new configuration set.

The tests are sensitive to many errors attributable to the PA system, caliber (figure 14) and the probing system. The primary objective is to determine the practical performance of the complete PA system.

In order to be used as a reference for future measurements, the caliber was calibrated on a high precision CMM machine (Nikon Altera CMM).

ISO 10360-2 specifies three uncertainties: volumetric length measuring uncertainty (MPEE); volumetric probing uncertainty (MPEP); and volumetric scanning error (MPETHP). MPE is the acronym for Maximum Permissible Error [24].

The calibration measurement must take place in the area where the future parts will be measured, so that the encoders can be approximated in the same position.

Three precision spheres of 30 mm (ISO recommends spheres between 10 and 50 mm in diameter) with form and diameter certification is used to verify PA system uncertainty (MPEP) – figure 13. Measurements are taken in 3 different locations within the PA system's measurement volume for the test. For each of the 3 locations, the sphere center position reported at the origin of the plate (bottom left corner, Figure 14) is measured 25 times for a total of 75 measurements. All 75 measurements must be within the stated tolerance specified by the manufacturer. The measured results are shown in Table 1, where MPEE$_1$ is the volumetric length measurement uncertainty (MPEE) before the start of the calibration and MPEE$_2$ is after tthe calibration process.

Table 1. Experimental date

| No | MPEE$_1$ [μm] | MPEE$_2$ [μm] |
|---|---|---|
| 1 | 21 | 2 |
| 2 | 24 | 3 |
| 3 | 19 | 1 |
| … | … | … |
| 23 | 18 | 3 |
| 24 | 25 | 2 |
| 25 | 22 | 2 |

TThe average value of the measurements was: MPEE$_1$ = 21,3 and MPEE$_2$ = 2,05 μm.

## 4. CONCLUSIONS

In the work, the following things were done experimentally:

- Additional equipment of the PA system has been developed so that precision measurements can be made;
- A standard caliber was used to calibrate the PA system, depending on the type of measurements to be performed;
- Measures have been made to test the supplementary equipment added to the PA system so that the new method can be validated;
- Following laboratory tests, the accuracy of the PA system has increased approximately 10 times. We can not know whether this value is repeatable over time, if it is validated on an industrial basis, and is correct for any type of complex geometry parts because lab

measurements were only linear, roughly one axis.

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