A NEW CALIBRATION SYSTEM FOR SELF-CENTRING PROBES AND ANALOG PROBES MOUNTING OPTO-ELECTRONICAL SENSORS

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Abstract:
A new system for the calibration of analog probes for coordinate measuring machines and self-centring probes for machine-tools is presented in this paper. The aim is to describe the proposed method to know the measuring errors of these probes out of machine. The process and the results obtained in different tests carried out on our own-developed probes are shown. The final goal is to obtain a calibration procedure that allows to know the accuracy of these systems in a quick and reliable way in order to guarantee their adequate performance.

Keywords: Analog Probe, Self-Centring Probe, Calibration Cube, Position Sensitive Detector (PSD), Coordinate Measuring Machine (CMM), Machine-Tool.

1. Introduction
In this communication a new calibration system for Coordinate Measuring Machine (CMM) analog probes and Machine-Tool (MT) self-centring probes is presented. This method allows to know the accuracy of these systems in a quick and reliable way out of machine.
Self-centring probes are part of a new concept to verify MT. They are designed to measure, in an efficient and quick way, the position of spheres mounted on a reference artefact (ball artefacts [1,2]) whose positions have been previously calibrated on a CMM. Placed in the MT spindle, the coordinates of the ball centres are obtained by moving and touching the spheres with the probe. The coordinates from the probe and the MT are compared in order to calculate the errors in the MT. On the other hand, analog probes mounted on a CMM are designed to measure a large density of points along a programmed trajectory by combining the measurements of the probe and its position in relation to the CMM reference system. Nevertheless, these probes, although different, can both integrate the same kind of opto-electronical sensors and be calibrated by very similar procedures and artefacts as it will be shown.

2. Self-centring Probes
An Angular Self-Centring Probe has been developed in our University. This probe mounts three rotationally movable styli with spherical probe tips whose angular displacements are measured by optical sensors. When probing the reference spheres, the three styli rotate around their axes. These axes and the styli spring capability have been realised by high precision flexure pivot elements. The probe was initially developed using incremental optical encoders as the displacement sensors because provide high resolution and accuracy. However, they make the probe large and costly, so a LED+PSD system has been studied as an alternative.

Fig. 1: Self-centring probe on a MT while measuring a balls artefact (left) and scheme (centre).
Though different alternatives are possible (Laser+CCD, LED+CCD, Laser+PSD, etc), the LED+PSD combination presents a very good cost-accuracy-resolution relationship. Position Sensitive Detectors are opto-electronical devices that provide an analog output directly proportional to the position of a light spot on its detection area. The final probe design integrates three 1D PSD (S3932 from Hamamatsu) and three infrared LEDs (L2791-02 from Hamamatsu).

During the process design we had to cope with different problems such as the coupling effect between background light and temperature, the optimal operating distance, or the non-linear behaviour near borders.

2.2. Analog Probes

Previously to the work presented here a six degrees of freedom analog probe had been designed and manufactured in our University using six LVDT (Linear Variable Differential Transformer) sensors (Fig. 2 left). The main feature of this probe was its high measuring range (±2mm). This probe was used to check the calibration system latterly described. As a first approximation a three-spheres nest instead of a spherical tip was mounted in this probe, this also enabled to use it as a self-centring probe. This fact does not affect metrological performance of the probe and allows to use the two calibration cubes latterly described. At this moment a second prototype with three 2D PSD and six LVDT sensors is being developed (Fig. 2 right).

3. Calibration system and procedure

This calibration procedure allows to calculate the error probes by comparison of the coordinates provided while measuring a standard artefact (calibration cube) with the real coordinates of this artefact [3] (previously calibrated on a high precision CMM). Also, the geometrical parameters of the probes could be best-fitted and their accuracy improved from these data.

Some previous tests mounting a sphere on a CMM head and moving it to known positions and comparing them to the coordinates given by the probe were carried out. The main problem of these tests was the lack of positioning repeatability of the CMM. That fact did not affect to the probe accuracy determination but made impossible to know its repeatability with precision.

3.1. Test Set-Up

Apart from the new standard artefact, a device (test set-up) to place the probe in relation to the calibration cube was developed. The probe is mounted at a moving part that moves up and down thanks to a motion system (Fig. 3 left). When the probe is up, the position of the cube can be changed. When the probe is down it rests on a very repeatable (±0.1µm) positioning system based on the contact between three cylinders and three pairs of spheres (kinematic coupling) where the measuring is made. A transformation matrix between the reference systems of the probe and the cube has to be calculated in order to compare the calculated coordinates to the calibrated ones.
3.2. Calibration Cube
This calibration device (Fig. 3 centre) is a kind of miniature ball cube with spheres fixed to its surfaces. Several sets of locating elements (6 pairs of 5mm spheres) exist for every main sphere (22mm diameter) which precisely positions the device on the test set-up base plate (resting on 3 cylinders). The locating elements and the spheres to be probed have different relative positions and orientations in each face. So by placing the cube on the base engaging different locating elements, the spheres centres cover a range of ±2mm in X, Y and Z, enough to characterize precisely the probe performance inside all its measuring range.

3.3. Calibration Nest
Since the usual configuration of an analog probe consists of a spherical tip mounted at the end of the stylus, the test cube was redesigned in order to substitute every 22mm diameter ball by a three-spheres nest where placing the spherical tip of the probe (Fig. 3 right) in a very repeatable way. The positions of such spheres were calculated to be able to calibrate probes with different tip diameters in a measuring range from ±0.2mm to ±3mm. The calibration procedure is similar to the one previously explained. On the other hand, the possibility of orientating in a different way while maintaining the contact between the tip and the spheres-nest also exists. In that case, the coordinates measured by the probe should remain the same in spite of its different orientation because the position of the stylus tip centre has not changed at all.

4. Experimental analysis and results
Both kinds of probes have been calibrated using the calibration cube technique. The tests were made in laboratory conditions, controlling the temperature and isolating the system, in order to avoid possible dilatation problems in the test set-up or in the cube.

The results obtained for the deviations of values indicated by the angular self-centring probe from the values of the calibration cube in X, Y and Z are shown in Fig. 4. The probe with the optical encoders not only shows deviations lower than ±0.6μm but a repeatability better than 0.5μm in the three axis. Nevertheless, after comparing the results from the LED+PSD measuring system and the encoders
system while the probe was mounted on the CMM, it was observed than the errors using the PSDs are higher than 4μm in some positions, whereas these error are always lower than 3μm using the encoders. This slight loss of accuracy using the PSDs could be improved with a more detailed correction of the PSD repeatable linearity error.

On the other hand, the six degrees of freedom analog probe shows deviations of about ±4μm and a repeatability of about 1μm (Fig. 5) while measuring the calibration cube, so the differences in the results between both probes are very clear. This is due to the probes and not to the calibration system itself. The self-centring probes were designed with a configuration that allows only three degrees of freedom that are measured with high-accuracy sensors (linear encoders). However, the six degrees of freedom analog probe uses less accurate sensors (LVDTs) and generates larger probing forces. Moreover, its geometry is more complex, what makes more error sources appear during its parameters determination and mathematic modelling. These are the main reasons why its performance (accuracy and repeatability) shows worse results.

![Fig. 5: Deviations of values indicated by analog probe from the values of the Calibration Cube in X, Y, and Z.](image)

Anyway, the calibration system itself shows a very good performance, mainly referring to its stability and repeatability. This allows to attribute only a very small part of the calculated errors to the method itself. Only some external influences (temperature variations) could affect the system, although, if the measuring process is quick enough, these influences become negligible.

5. Conclusions
The presented calibration systems allow to know the errors of a self-centring or an analog probe in the three Cartesian axes at representative points along all their measuring range. Moreover, these systems show a high reliability that allows to isolate the errors due to the probe from other errors that could be attributed to the method. On the other hand, it has been shown the possibility of using low cost optoelectronic sensors (PSD) for the developing of new probes when the accuracy requirements are not very high.

6. References

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