A 5 degrees of freedom µCMM

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Abstract

Micro- / nano- coordinate measuring machines (CMMs) can today reach an accuracy level of a few nanometers. Those machines have usually a simplified design with a fixed vertical stylus to fulfill the Abbe principle which restricts their measurement possibilities to vertical holes.

The 5 degrees of freedom µCMM described in this paper opens the measurement capability to almost any 3D part geometry. A tray with 2 rotation axis driven by piezo motors was designed and installed onto the 3D stage of our METAS ultra-precision µCMM. The workpiece can thus be tilted and displaced to any position. Since the accuracy of the used rotation stages does not match the nanometer accuracy of the µCMM, additional reference objects are added onto the sample holder to track the exact position in space of the workpiece, thus barely impacting the overall measurement accuracy of the machine.

1. Introduction

During the last decade, several national laboratories and industries have developed highly accurate micro- / nano- coordinate measuring machines [1] [2]. In order to reach an accuracy level in the nanometer range those machines have usually a simplified design with a fixed vertical stylus in order to fulfill the Abbe principle. With this styli configuration the measurement possibilities are restricted to vertical holes. The use of multiple styli probes [3] can extend the measurement capabilities to side features such as side holes, but introduce a considerable Abbe offset, thereby sacrificing some accuracy. Only very few micro-probe head systems are capable of using multiple styli probes and so far there are also no indexing probe heads available for µCMMs.

2. Concept of the 5 axis CMM and implementation

In order to overcome the restrictions mentionned above and to widen the application field of our µCMM at METAS, two rotationnal stages, mounted in series, which carry the workpiece have been added onto the tray of our µCMM. As shown in figure 1, the workpiece under measurement, here a dice, can then be brought to almost any position so that the probe can access all the features to be measured. Since the two rotational stages do not reach the nanometer accuracy of the µCMM, additional reference spheres are added onto the sample holder in order to determine the exact position in space after a workpiece rotation. Thus the stages do not need to be extremely precise but must only hold a given position precisely.

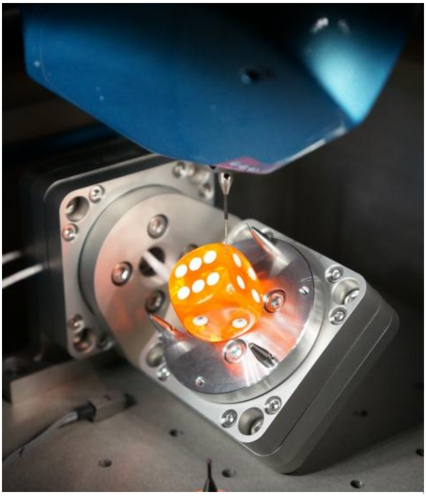

Figure 1: the two rotational piezo stages carrying the workpiece and three reference spheres surrounding it

Piezo motors have been chosen because they are capable of a fine positionning without sacrificing on their wide course. They have a high stiffness and dissipate almost no energy when holding a position. Their size is also quite small and fit onto the tray of our µCMM.

A series of basic commands have been implemented so that the stages can be driven directely from our measuring software. Software limit switches were implemented such that the movement of the vertical drive does not exceed ±100°.

3. Characterisation of the rotational stages

The rotation stages include angular encoders with 1 µ° resolution. Looking at the angular reading when a stage is running in closed loop, the position deviation is less than ±0.2 µ°. According to the angular encoder reading only, the repositionning of a stage achieves the same accuracy.

Long time drift has been investigated by continously measuring the position of three reference spheres mounted onto the sample holder. The configuration with the two stages in series is of course quite sensitive to temperature changes. Neverthless, once the temperature of the system is stabilized to ±0.02 °C, the usual measuring conditions with our µCMM, the workpiece position was held stable within ±10 nm measured at 17.5 mm from the rotation center (sphere locations).

The repeatability of the reference sphere positionning was measured to be better than ±100 nm in the rotation plane and ±50 nm perpendicular to the rotation plane when driving the stages to ±10 ° and then back into the measurement position. When moving a full 360° the repeatability was unfortunately in the range of ±1.0 µm.

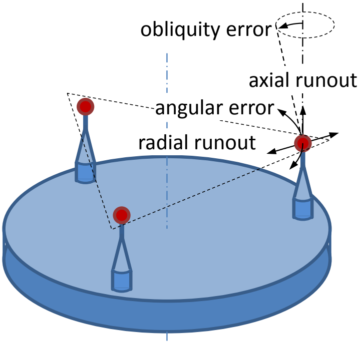

Figure 2: types of error characterized

The position of the three reference spheres were measured over 360° every 10°. The computed absolute positionning errors are given in figure 2 and 3. The radial and axial runouts were of similar magnitude of less than ±1.2 µm. The angular positionning exhibits a quite large systematic error of up to ±0.035 °. Once corrected, the angular accuracy is in the range of ±0.012 ° and is in the same order as the obliquity error.

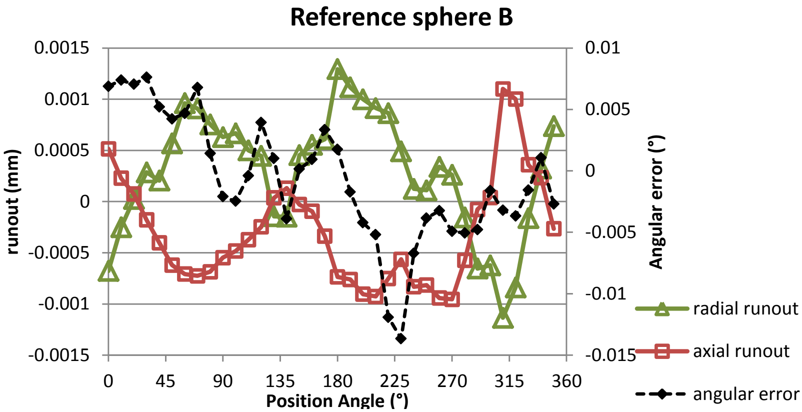

Figure 3: Positioning error of the horizontal stage calculated from the measured reference sphere centre.

To summarize, the rotation stages lead to a positionning precision within the measuring volume in the order of ±1.5 µm which seems to be due to the bearings inside the stages. Nevertheless, once in position and tempered, the system is stiff and does not drift more than ±10 nm.

4. Measurement example

Figure 4 is showing a nice gear wheel with side index shaft and square center hole which can now easily be measured with our µCMM. The reference spheres surrounding the wheel were probed using scanning with more than 250 points each and could be relocated with less than 10 nm uncertainty which ensures that the features measured on the side and back of the wheel can be linked to the measured features on the front of the wheel within the same accuracy.

Figure 4: gear wheel with a side index shaft and square center hole measured with our µCMM fitted with a Ø = 0.2 mm probe

5. Conclusion

The system of two rotational stages added onto our 3D µCMM widens the measuring capabilities of our machine. In order to maintain the accuracy of the machine after a rotation stage movement, 3 or more reference spheres were added to exactely relocate the position of the workpiece. The machine geometry still fullfils the Abbe principle at any measurement point. The measurement example shows that the main accuracy compromise is due to the stitching of the several workpiece positionings.

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