Scanning results and repeatability testing of the TriNano ultra precision CMM

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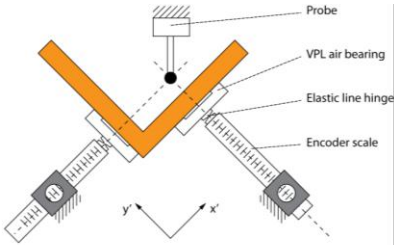
Abstract

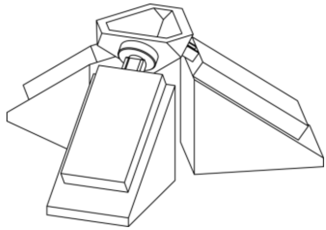
A novel coordinate measuring machine has been developed to provide a cost effective solution for measuring micro components with a 3D uncertainty of 100 nm. This paper summarizes the design aspects and part of the verification experiments concerning repeatability and surface scanning using a Gannen XP 3D probing system.

Figure 1. Left side: TriNano CMM (artist impression), Right side: measurement using the Gannen XM probe.

1 Operating principle

In the TriNano, the workpiece moves in three directions with respect to the stationary probe by means of three identical linear translation stages. The stages are positioned orthogonally and in parallel and support the workpiece table via vacuum preloaded (VPL) porous air bearings as shown schematically in two dimensions in figure 2. From this figure the operating principle of the TriNano becomes clear. A linear translation of a stage is transferred via a VPL air bearing to the workpiece table. Translations of the workpiece table with respect to the linear stage in other directions than the translation of the stage are decoupled by the VPL air bearing. In this manner, the three stages independently determine the position of the workpiece table in three dimensions. On each linear stage, the scale of an optical linear encoder is mounted. At the point of intersection of the measurement axes of these encoders, the probe tip is located. As the orientation of the encoder scale does not vary with respect to the probe, as can be seen in figure 2, the TriNano complies with the Abbe principle over its entire measurement range. As a result, rotations of the workpiece table will have





little effect on the measured dimension.

Figure 2. Schematic representation of the operating principle.

Instead of a conventional orientation of the machine axes, i.e. two orthogonal axes in the horizontal plane and a third vertically oriented axis, the three axes in the TriNano are oriented such that each stage experiences an equal gravitational load. This orientation of the axes combined with the operating principle results in identical translation stages which can be produced at a lower cost.

This parallel configuration allows a low and equal actuated moving mass of each stage with short and stiff structural loops. On machine measurements show that the lowest natural frequency in the positioning loop is 75 Hz. This allows a high control bandwidth, required for scanning measurements of micro parts with a velocity of 1-2 mm/s.

2 Thermal stability and compensation

Thermally induced errors are often the largest contribution to the total error budget in precision measurement equipment [2,3,4]. However, certain straightforward measures can be taken to reduce these thermally induced errors, such as minimizing and controlling the heat flow and decreasing the thermal sensitivity of the machine. In the Trinano, a pneumatic weight compensation system is applied to minimize the heat production in the actuators. Furthermore, the relatively large granite frame results in a long thermal time constant of the frame parts in the metrology loop. The other key components in the metrology loop are the probe holder and the workpiece table. Instead of applying a low expansion material like invar, these components are made of aluminium and compensation for thermal expansion is implemented. The temperature variations for the linear compensation model are measured by NTC's which are distributed in the metrology loop. The main advantage of NTC's compared to other sensors like PT100's is their resolution [5] which is better than 0.1 mK.

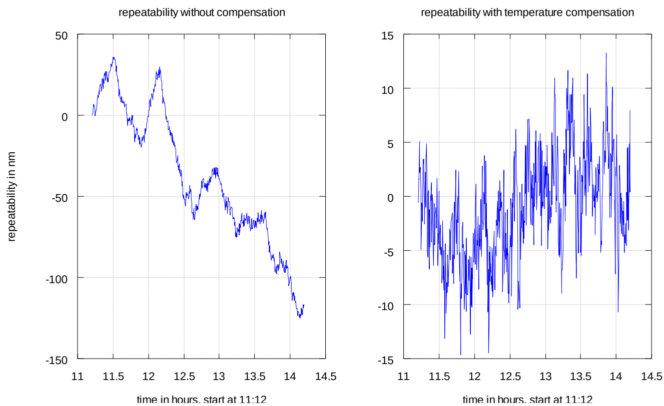


Figure 3. Left: Uncompensated single point repeatability values. Right: Single point repeatability with compensation for thermal expansion.

Single point repeatability of the TriNano CMM using a Gannen XP 3D probing system is verified on a steel gauge block. The results include the disturbances of all parts of the metrology loop, e.g. thermally induced errors and the stability of the vacuum preloaded air bearings. More information about the stability of the air gap of the vacuum preloaded air bearings in the metrology loop has been published previously [6].

Measurements show that, after compensation, a peak-to-valley deviation of 28 nm over a 3 hour measurement can be obtained (without covers). The uncompensated and compensated measurement results for single point repeatability are shown in figure 3.

3 Scanning measurements

To verify the dynamic behaviour of all components in the metrology loop, including a Gannen XP probe, scanning tests are performed at a scanning velocity of 1 mm/s. The measurement object is an optical flat which is scanned using a Gannen XP probe with a ruby tip of 0.3 mm in diameter. The top surface of the optical flat is measured using two square patterns, as shown in the left-hand graph of figure 4. From this graph it can be seen that the optical flat was slightly tilted during the measurement.

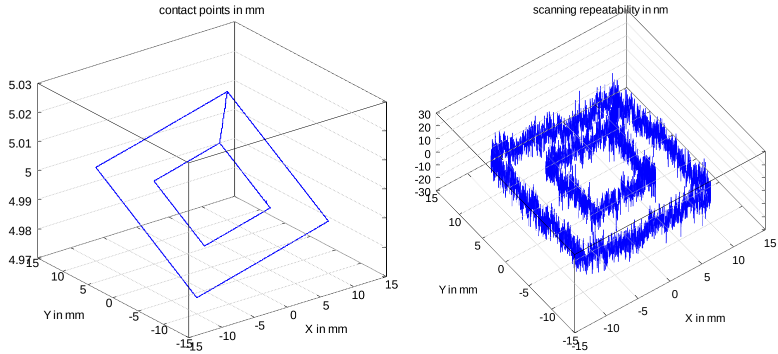


Figure 4. left: Contact points scanning cycle. right: Repeatability of two subsequent scanning cycles.

The same pattern on the optical flat was measured twice. The difference between all corresponding measurement values without averaging of both scanning cycles is within a band of ± 20 nm, as shown in the right-hand graph of figure 4.

4 Conclusions

Two important aspects which determine the performance of this CMM are stability and the dynamic behaviour during scanning. After compensation for thermal expansion, single point measurements show that the top-top deviation is within 28 nm during a 3 hours period. The difference between repeated scanning cycles at 1 mm/s is within a band of ± 20 nm.

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