Isara 400: Enabling Ultra-precision Coordinate Metrology for Large Parts

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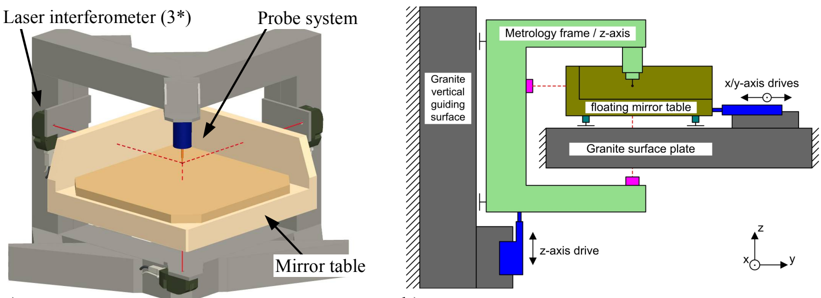
Abstract

The current work describes the design and realization of a new ultra-precision CMM with an unprecedented ratio of measurement volume vs. measurement accuracy, the "Isara 400", which enables the measurement of larger products (up to 400 mm) in full 3D with nanometer-level accuracy. In addition, a newly developed miniaturized 3D tactile probe system is presented.

1 Isara 400 design

The new Isara 400 CMM features a measurement volume of 400 x 400 x 100 mm. For all axes, the targeted 1D measuring uncertainty is 45 nm (k=2), whereas the expected full-stroke 3D measuring uncertainty totals 100 nm (k=2).

To achieve these specifications, the Isara 400 metrology concept conforms to the Abbe principle in 3D over the entire measuring volume: the measurement of the axes displacements is always in line with the functional point (i.e. the measuring probe). This removes the most significant errors caused by rotations of the linear guides.



a) b)

Figure 1: a) 3D Abbe principle; b) Design concept of the Isara 400 CMM

Figure 1 shows the concept of the Isara 400. The work piece to be measured is placed on a mirror table. This table is supported by air bearings and free to move in two horizontal directions (X and Y). Vertical relative motion (Z) is obtained by moving the complete metrology frame up and down. Varying work piece masses thus have no influence on the positioning of the vertical drive. The relative displacements of the mirror table and the metrology frame are measured by three laser interferometers, mounted in the metrology frame, which remain aligned with the probe tip.

1.1 Mirror table and XY-drive

The mirror table of the Isara 400 is a monolithic Zerodur part with three reflective sides. A silicon carbide (SiC) product table serves as an interface between the product and the mirror table. The three supports of the product table are placed directly above the three air bearings which support the mirror table, so that the weight of the product and product table does not cause additional deformation of the mirrors. The coupling between the mirror table and the X-axis drive is described in more detail in [1]. Figure 2 shows the design of the mirror table and X-axis, as well as a photograph of the realized assembly with a temporary aluminum mirror table.

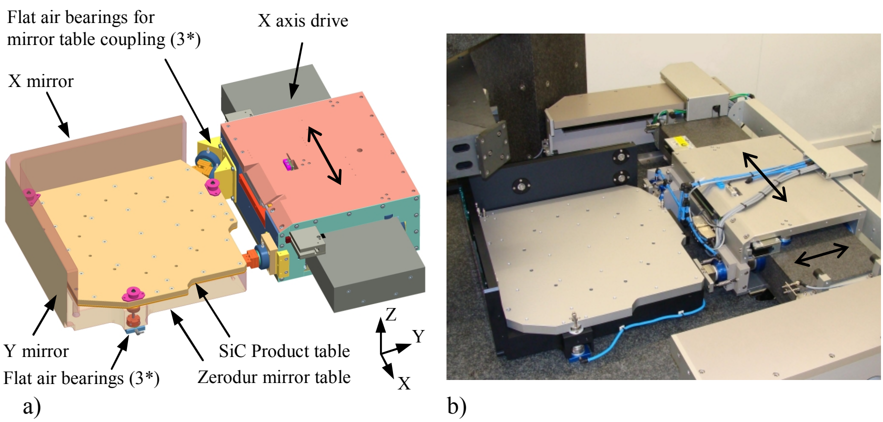
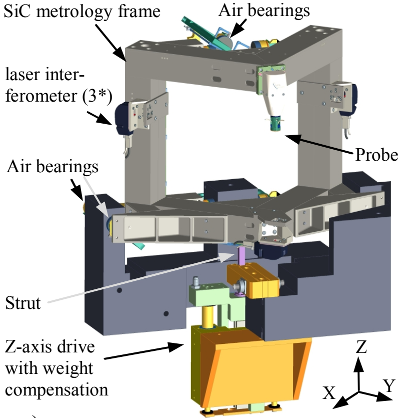


Figure 2: a) Design of floating mirror table and X-axis drive; b) Realized assembly with temporary aluminum mirror table.

1.2 Metrology frame and Z-drive

The metrology frame must maintain the mutual position and alignment of the probe and the three laser interferometers with high stability. This frame is an assembly of SiC beams (figure 3b), designed to achieve high stiffness, low mass and good thermal stability. The metrology frame is statically determined in six degrees of freedom by means of five flat air bearings and a strut joint to the Z-drive. A kinematic probe mount enables a quick and reproducible exchange of probes.



a)

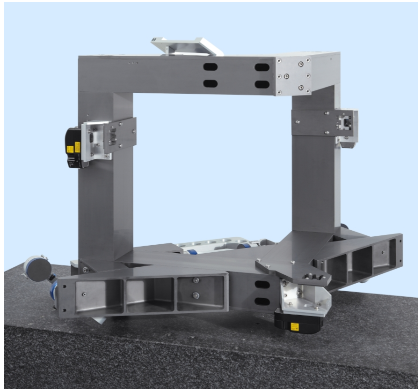


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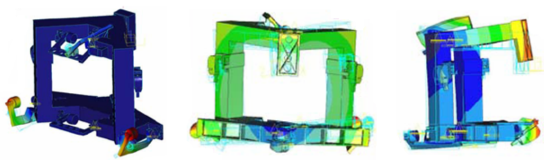
Figure 3: a) Design of metrology frame and Z-axis drive. Granite guiding surfaces are only partially shown; b) Realized SiC metrology frame.

The Z-drive, which is placed below the metrology frame, connects with a strut directly through the centre of mass (see figure 3a). The Z-drive contains an air bearing guide for the linear motor, with an integrated pneumatic weight compensation system. As a result, the required force from the linear motor to hold the metrology frame in place is minimized; the motor only needs to generate force during acceleration and deceleration, thus dramatically reducing the resulting heat generation.

The design of the metrology frame was optimized to be both stiff and lightweight. Figure 4 shows results of both a theoretical modal analysis and a first measurement, where the frame was excited while the frequency spectra of the three laser interferometric displacement measurements against a fixed target were measured.



a) 160 Hz 230 Hz 380Hz

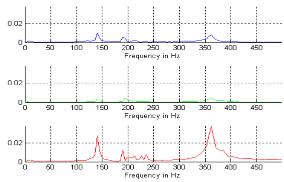


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Figure 4: a) FEM modal analysis of SiC metrology frame; b) frequency spectrum of displacement measurements against fixed target during excitation of frame.

2 Triskelion ultra-precision probe

Ultra-precision coordinate metrology in full 3D requires probe systems with low measuring uncertainty, low probing force and preferably small probe tips to enable the measurement of small features. The newly developed "Triskelion" probe system (figure 3a) features a stylus which is elastically suspended, resulting in low probing forces as the tip deflects during probing measurements. The stylus consists of a stiff tungsten carbide shaft with a small ruby sphere (Ø 0.5 mm). The flexures of the suspension are manufactured from a monolithic foil, which also features three targets for the capacitance sensors. The measured displacements of these targets are used to determine the X, Y and Z deflections of the probe tip. The complete probe body is made of invar to ensure good thermal stability.

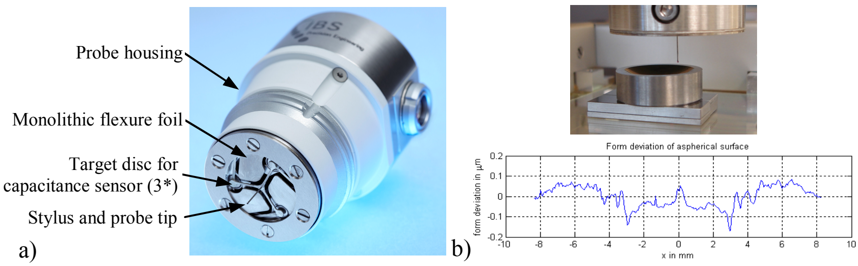
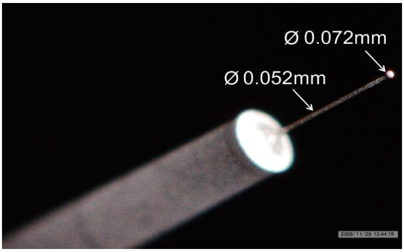


Figure 5: a) Triskelion ultra-precision probe. b) Aspheric mould measurement

The sensitivity calibration of this probe system is performed on an ultra-precision CMM. For all measurements up to 5 μm tip deflection, the absolute measurement errors are < 10 nm per axis of the coordinate system and < 15 nm in 3D. Figure 3b) shows a photograph of the measurement of an aspherical mould insert and the corresponding form error of a profile measurement across the center, which is obtained from the measurement after subtraction of the theoretical asphere.

A miniaturized version of the Triskelion probe, featuring a stylus with a probe tip diameter of about 70 μm, is currently being realized. The small tip will enable measurements of very small features, such as the inside diameters of very small holes, up to 1 mm depth. The suspension foil has been redesigned to further reduce the probing forces, so that the contact stress between the small tip and the work piece does not cause surface damage. Figure 6 shows a photograph of the miniaturized stylus, as well as a comparison picture of the two Triskelion probes.



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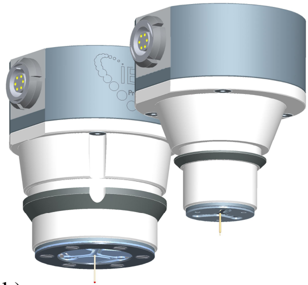

b)

Figure 6: a) Photograph of miniaturized stylus. b) Design of miniaturized Triskelion probe (first version shown in background for comparison)

3 Conclusion

The new Isara 400 CMM is the latest development of IBS Precision Engineering for coordinate metrology of large, complex parts with nanometer level measuring uncertainty. The expected 3D measuring uncertainty is 100 nm within the complete measuring volume of 400 x 400 x 100 mm. Tactile probes, such as the presented Triskelion ultra precision touch probe, as well as other possible (optical) probe systems can be used to perform scanning or point measurements. The presented machine, see figure 7, provides a technology basis which can be adapted and optimized for specific user requirements.

Figure 7: Overview of the realized Isara 400 CMM

Acknowledgements

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References:

[1] Donker R., Widdershoven I., Brouns D., Spaan H., "Realization of Isara 400: a large measurement volume ultra-precision CMM", Proceedings of the ASPE annual meeting, 2009.