REALIZATION OF ISARA 400: A LARGE MEASUREMENT VOLUME
ULTRA-PRECISION CMM

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INTRODUCTION
In various fields of manufacturing and research, a growing demand for ultra-precise 3D measurement of large products exists. To fulfill this demand, IBS Precision Engineering has developed a new ultra-precision CMM with an unprecedented ratio of measurement volume vs. measurement accuracy. The design concept of this machine, the Isara 400, was presented at the ASPE spring topical meeting 2009 [1]. The current work presents various design details and the realization of the Isara 400.

ISARA HISTORY
In collaboration with Philips Applied Technologies, IBS PE previously developed the Isara CMM, an ultra-precision 3D Coordinate Measuring Machine, based on the design by Ruijl [2], with a measuring volume of 100 x 100 x 40 mm and a 1D measuring uncertainty of 15 nm, see figure 1.

In response to the demand for 3D measurement of larger products with features that require nanometer measuring uncertainty, the new Isara 400 ultra-precision CMM is developed.

ISARA 400 CONCEPT
The new Isara 400 CMM has a measurement volume of 400 x 400 x 100 mm. Three plane-mirror laser interferometers are applied as measuring systems for the machine axes. The interferometers each measure against the sides of a mirror table, on which the work piece is mounted. These interferometers are mounted in a single body metrology frame, which also holds the probe system. The laser beams are aligned to the probe tip and their mutual alignment does not change during movement of the axes, thus fulfilling the Abbe principle [3] in 3D within the complete measuring volume.

In the configuration of the translation axes, a machine concept was chosen in which the variable product mass does not need to be moved vertically (figure 2). The product is mounted on the mirror table, which moves only in X- and Y-direction over a granite plate, guided by air bearings. The complete metrology frame moves in Z-direction, with guiding provided by air bearings against a vertical granite surface. This metrology frame contains the three laser interferometers and the probe, thus maintaining the Abbe alignment. The design of several key components is described in the next sections.

MIRROR TABLE
The mirror table of the Isara 400 is a monolithic Zerodur part with three reflective sides (figure 3). An additional product table is used as an interface between product and mirror table. This Silicon Carbide (SiC) product table was designed to be both light and stiff. The three supports of the product table are placed directly above the three supports of the mirror table, so that the weight of the product and product table does not cause additional deformation of the mirrors. The mirror table is supported by three flat air bearings, whose preload is provided by the weight of the mirror table assembly with product.
The coupling between the floating mirror table and the X-carriage must define three degrees of freedom (X, Y and Rz) and allow for differences in thermal expansion. As the coupling is directly connected to the mirror table, it must be very compliant for parasitic motions between the mirror table and the X-carriage (Z, Rx and Ry): such parasitic motions should not cause deformations of the mirrors. Especially the flatness of the Z-mirror is sensitive to forces exerted by the coupling due to such motions. Parasitic motions may result from non-flatness and non-parallelism of the X-Y guide ways and sagging of the guideways because of the moving parts. Furthermore, the coupling must deal with different fly heights of the floating table resulting from different product loads. FEM calculations on the original coupling with three struts [1] show large deformations of the mirrors.

As can be seen in figure 4, an applied Ry rotation on the X-carriage slide results in deformation of the Z-mirror. For example, the sagging of the X-axis guideway will cause a rotation Ry of 25 µrad, which results in a mirror deformation of 200 nm. Most of the parasitic motions will reproduce during the X and Y movements, so their influence will be measured and corrected during calibration of the mirrors, which will be performed on the machine. Nonetheless, variable mirror deformations should be avoided.

In the new design, shown in figure 3, the three struts are replaced by three air bearings. This configuration eliminates influences from vertical motions and also thermal effects will not lead to forces acting on the mirrors, because the frictionless coupling of the bearings cannot transmit any forces in Z direction. The parasitic Ry motions will only act on the two bearings at the back side, Rx motions will act on all three bearings. An error budget was made of all possible parasitic rotations and the worst case situation was used as input for a FEM analysis. With this new design, the effect on the flatness of the three mirrors was found to be < 1 nm.

As the three bearings do not move, the preloading can be achieved by adding extension springs directly to the bearings. These compliant springs will cause a force-closed preload for the bearings. The influence of those springs on the mirrors was also calculated and found negligible.

The metrology frame, shown in figure 5, must maintain the mutual position and alignment of the probe and the three laser interferometers with high 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. All bearings are preloaded with flat air bearings on the opposite side. As the machine is a multi-probe machine, it contains a kinematic probe mount for a quick and reproducible exchange of probes. The metrology frame is an assembly of SiC beams; figure 6 shows several components.

**FIGURE 6: Photo of SiC metrology frame components (courtesy of Coorstek).**

The Z-drive moves the metrology frame in vertical direction. It is placed below the metrology frame and connects with a strut directly through the centre of mass. Around the coupling strut an emergency brake is placed which can hold the metrology frame in place by clamping the strut, for example when no electric or pneumatic supply is present.

The Z-drive contains an air bearing guide for the linear motor, with an integrated weight compensation system, see figure 7.

**FIGURE 7. Photograph of realized Z-axis drive with weight compensation system.**

This bearing system consists of two shafts; each shaft is guided in two cylindrical air bearings (bushings) with different diameters. The space between the two bushings is sealed by the two bushings, thus serving as a pressure chamber. By supplying exactly the right air pressure, the weight of the metrology frame can be compensated and equilibrium is achieved. As a result, the required force from the linear motor to hold the metrology frame in place is minimized. The heat generation of this drive is therefore very low. The realized Z-drive shown in figure 7 is currently being tested.

**TRISKELION ULTRA-PRECISION PROBE**

Conventional touch probes are generally not suitable for ultra-precision coordinate metrology, due to their relatively high measuring uncertainty and large probing forces and the ability to measure small features is limited, due to the relatively large probe tips which are applied. Several different ultra-precision touch probes developed over the past years [4,5,6,7] share a common design feature: the stylus is elastically suspended, allowing deflection of the probe tip and thus reducing probing forces. This deflection is measured by means of an integrated measurement system within the probe. Building on these previous efforts in the development of ultra-precision touch probes, the new 'Triskelion' probe system was developed (figure 8).

**FIGURE 8. Triskelion ultra-precision probe.**

The probe calibration was described in [1]. Absolute measurement errors are < 10 nm per axis of the coordinate system and < 15 nm in 3D.

Several product measurement have been performed, using the new probe system integrated into an ultra-precision CMM. Figure 9 shows a photograph of the measurement of an aspherical mould insert and the corresponding form error of the profile measurement across the center, which is obtained after subtraction of the theoretical asphere.
FIGURE 9. Aspheric mould measurement using the Triskelion probe.

MEASURING UNCERTAINTY OF ISARA 400
An extensive uncertainty analysis was performed to make an accurate estimation of the expected measuring uncertainty of the Isara 400 CMM. Some of the most important contributing factors are the uncertainty of the laser interferometers, the calibration uncertainty of the mirror table (flatness and perpendicularity), the stability of the metrology frame and the measurement uncertainty of the probe. For all axes, the expected 1D measuring uncertainty is 45 nm (k=2), whereas the full-stroke 3D measuring uncertainty totals 100 nm (k=2). Both values include contributions from the described probe system and are valid within the complete measuring volume of the machine.

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 10, provides a technology basis which can be adapted and optimized for specific user requirements. The machine will be operational by the end of 2009.

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REFERENCES