Development and performance demonstration of the NANOMEFOS non-contact measurement machine for freeform optics

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Abstract

This paper shows the machine concept, the realization and the test results of the completed NANOMEFOS non-contact measurement machine for freeform optics. The separate short metrology loop results in a stability at standstill of 0.9 nm rms over 0.1 s. Measurements of a tilted flat show a repeatability of 2-4 nm rms, depending on the applied tilt, and a flatness that agrees well with the NMi measurement.

1 Introduction

Applying freeform optics in high-end optical systems can improve system performance while decreasing the system mass, size and number of required components. The applicability of classical metrology methods is limited for freeform surfaces, which is currently holding back their widespread application. TNO, TU/e and NMi VSL have therefore developed the NANOMEFOS measurement machine [1], capable of universal non-contact and fast measurement of freeform optics up to ∅500 mm, with an uncertainty of 30 nm.

2 Machine concept

A cylindrical setup is applied, in which the optic under test is placed on a continuously rotating air bearing spindle, while a specially developed optical probe is positioned over it by a motion system. The optical probe enables high scanning speeds (up to 1.5 m/s), and its 5 mm measurement range captures the non-rotational symmetry of the surface. This allows for the stages to be stationary during the measurement of a circular track, reducing the dynamically moving mass to 45 g. This way, a circular track is measured several times to acquire sufficient data for averaging. The position of probe and product is measured relative to a metrology frame in a separate metrology loop.

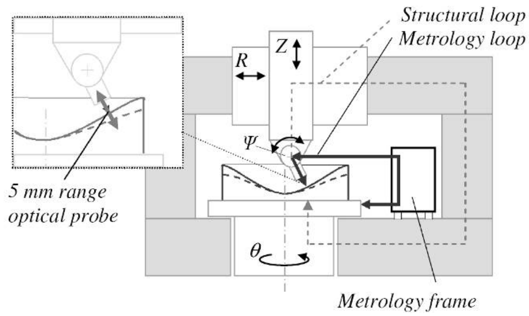

Figure 1: Machine concept

3 Machine design and realization

An air bearing motion system positions the probe relative to the product, with sub-micrometer uncertainty in the out-of-plane directions. Here, an accurate plane of motion is provided by directly aligning the vertical stage to a vertical base plane with 3 air bearings. Further, separate preload and position frames are applied throughout to minimize distortion and hysteresis, and the motors and brakes are aligned with the centers of gravity of the stages. A short metrology loop in the plane of motion of the probe is obtained by directly measuring the probe position interferometrically relative to a metrology frame. Mechanical and thermal simulations resulted in Silicon Carbide as the preferred material for this metrology frame. The error motion of the spindle is measured relative to this frame with capacitive probes.

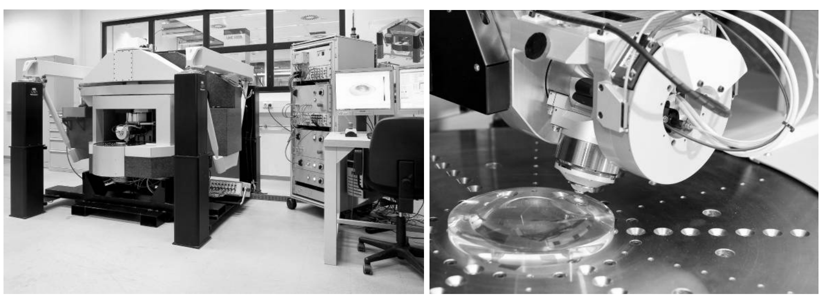

Figure 2: Measurement machine prototype and optical probe measuring convex lens

The optical probe [2] is a compact integration of a differential confocal system and an interferometer. The focusing objective and interferometer mirror are guided by a flexure guidance and actuated by a voice coil, with a closed loop bandwidth of 500 Hz and nanometer order servo errors.

4 Testing

The prototype realization, including custom electronics and software, has been completed. To test the stability, the probe is focused onto a stationary test surface (Figure 3, left). The metrology loop measures the probe position relative to the product, and the probe measures the distance to the product. The difference should be zero. Figure 3 (right) shows the measurement signals of the two parts of the loop. The difference is shown to be 0.9 nm rms over 0.1 s in the lower graph.

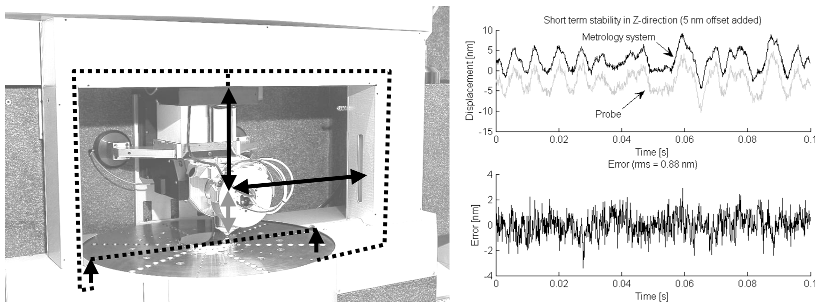

Figure 3: Stability at standstill

To demonstrate machine performance, a 100 mm diameter Zerodur optical flat has been measured. First, this flat has been measured with only 13 µm tilt. The spindle speed was 1 rev/s, which results in 250 mm/s scanning speed at the outer edge. Five revolutions were averaged per track, and the track spacing is 1 mm. The surface was measured three times, and each was compared with the average to determine the repeatability. Radial scans with a stationary product are taken before and after each measurement to compensate for the drift that accumulates during the scanning of the circular tracks. Without drift compensation, the repeatability is 8-9 nm rms. When the drift compensation is applied, this improves to 2 nm rms (Figure 4, left). The flatness of the surface was determined by NMi VSL to be 7 nm rms and 40 nm PV. The uncalibrated machine measures a flatness of 8-9 nm rms and 50 nm PV of the 13 µm tilted flat (Figure 4, right), which matches the NMi data well.

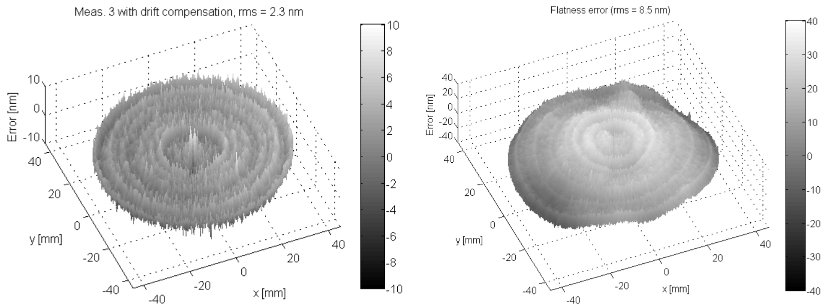

Figure 4: Repeatability and flatness of tilted flat measurement (13 µm tilted)

Next, the surface was tilted by 1.8 mm. Ten measurements again show a repeatability of 2-4 nm rms. The measured flatness is now 13-15 nm rms, with a clear measurement artifact at the centre, caused by the tilt dependency of the probe. This will be compensated for to nanometer level by a built-in PSD and novel calibration method [2].

Little post-processing has yet been applied to these values and no calibration data has yet been taken into account. Further calibrations and improved data processing will be carried out to improve these promising results, and the machine will be employed in high-end freeform optics fabrication at the TNO Optical Workshop.

Acknowledgment

This project is partially funded by the IOP Precision Technology program of the Dutch Ministry of Economic Affairs, and would not have been possible without the valuable contribution of many people from TU/e, TU/e GTD, TNO and NMi VSL.

References:

[1] Henselmans, R., *'Non-contact Measurement Machine for Freeform Optics'*, PhD Thesis, Technische Universiteit Eindhoven, ISBN 978-90-386-1607-0, 2009

[2] Cacace, L.A., *'An Optical Distance Sensor: Tilt robust differential confocal measurement with mm range and nm uncertainty'*, PhD Thesis, Technische Universiteit Eindhoven, to be published in 2009