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# Freeform optics measurements with the NANOMEFOS non-contact measurement machine

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## ABSTRACT

The NANOMEFOS non-contact measurement machine for freeform optics has been completed. 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.

**Keywords:** NANOMEFOS project, freeform, asphere, optics, non-contact, form, measurement machine, metrology

## 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. Local polishing and fast- or slow-tool-servo diamond turning enable the generation of these complex surfaces<sup>1</sup>. The applicability of classical metrology methods is limited for freeform surfaces, which is currently holding back their widespread application. TNO Science and Industry, Technische Universiteit Eindhoven and the Netherlands Metrology institute have therefore developed the NANOMEFOS measurement machine<sup>2</sup>, capable of universal non-contact and fast measurement of freeform optics up to Ø500 mm, with an uncertainty of 30 nm.

## 2. CONCEPT

A cylindrical setup is applied (figure 1), in which the optic under test is placed on a continuously rotating air bearing spindle, while a specially developed optical probe<sup>3</sup> 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.

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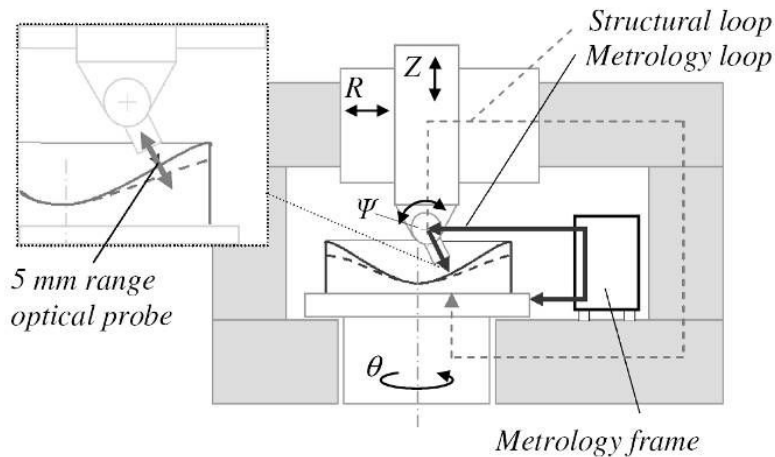


Figure 1: Machine concept with long range optical probe and separate metrology loop

### 3. DESIGN & REALIZATION

The realized machine is shown in figure 2. An air bearing motion system positions the probe relative to the product, with sub-micron 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. The optical probe 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.

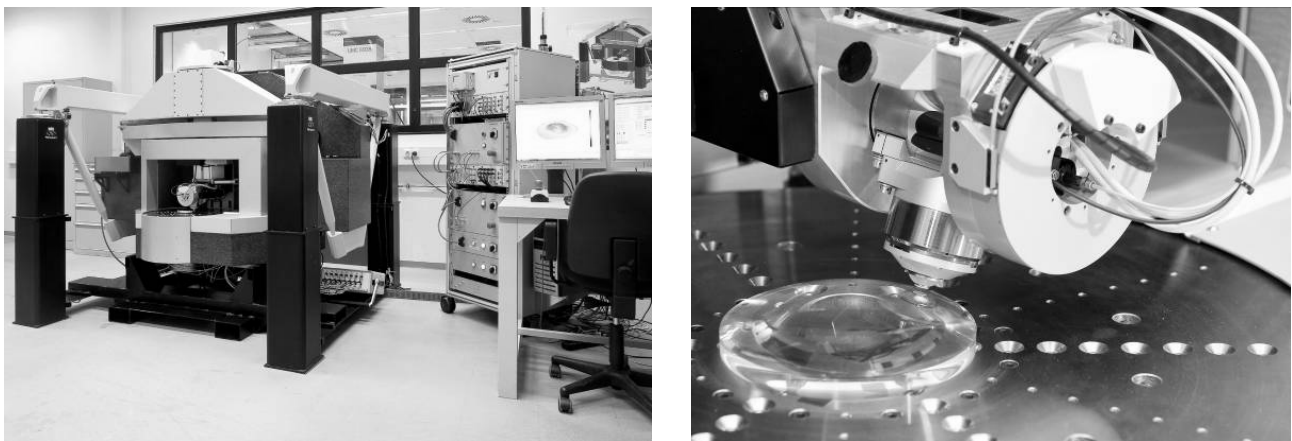


Figure 2: The NANOMEFOS measurement machine and measurement of a convex lens

### 4. RESULTS

The prototype realization, including custom electronics and software, has been completed. To demonstrate machine performance, a 100 mm diameter Zerodur optical flat has been measured (figure 3). With measurements at standstill, a noise level of 0.9 nm rms was shown over 0.1 s. Next, the full surface was measured with only 13  $\mu\text{m}$  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 total measurement time is 6 minutes. 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  $\mu\text{m}$  tilted flat (Figure 4, right), which matches the NMI data well.

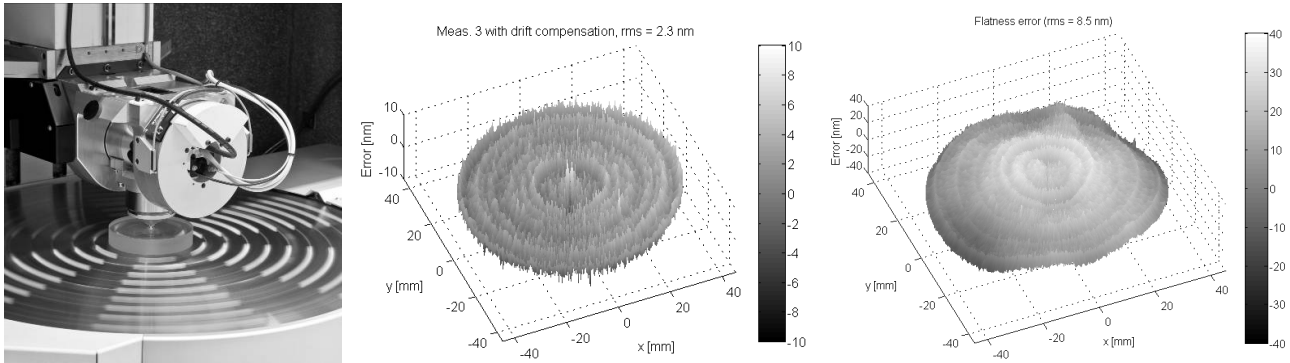


Figure 3: Tilted flat measurement and typical repeatability and flatness measurement result

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<sup>3</sup>. 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.

## 5. CONCLUSION

The design, realization and testing of the prototype, including the custom control software and electronics, has been completed with promising surface measurements. Further calibrations and software developments will be carried out to demonstrate the nanometer level uncertainty, and it will be employed in the freeform manufacturing and application research.

## 6. ACKNOWLEDGEMENT

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