Application Note: Motion & Sensing 27

Interferometric measurement of beam steering mirror

Angular measurements for calibration or closed-loop control

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Introduction

Advanced manufacturing methods such as precision laser cutting, photonics applications in the tele-communication field and highest resolution imaging setups at synchrotron facilities have one thing in common – they rely on highly accurate optical beam steering systems to guide the light from its source to the target position. Most of these systems, especially the ones for very energetic light, consist of multiple mirrors. These mirrors are aligned by precision motion stages, often with piezo or voice-coil drives and integrated sensors. However, even smallest motion errors of these stages or vibrations can lead to significant misalignment, as the beam paths can be quite long.

To ensure the demanded accuracy a contactless external sensor, which can measure multiple degree of freedom (DoF) motion with highest accuracy, is essential. Common angular measurement devices like e.g. auto-collimators lack the measurement bandwidth for dynamic closed-loop motion control and are very limited in the angular measurement range. Therefore, the following Application Note elaborates how the IDS3010 interferometer can overcome these challenges and enable ultimate precision in advanced beam steering setups.

3 Degree of Freedom Mirror Alignment on Piezo Nanopositioners

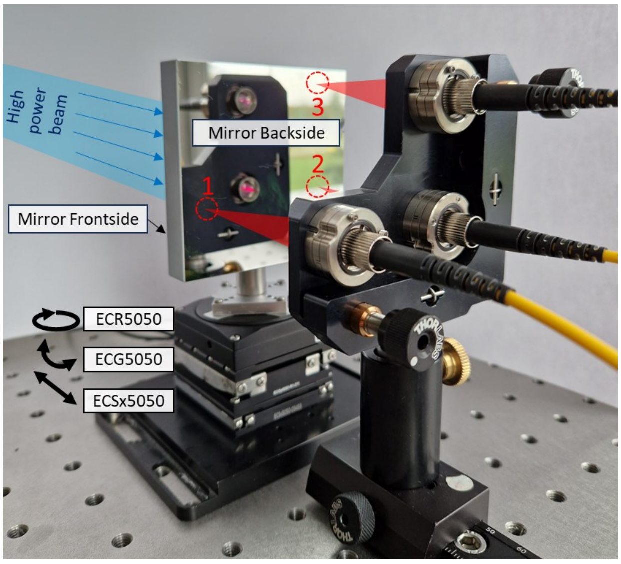

Figure 1: Sensor head setup for simultaneous 3 DoF measurement on highly reflective mirror backside. Mirror mounted on ECSx5050, ECG5050 and ECR5050 nano positioning stages.

Figure 1 shows a typical angular measurement setup, which includes 3 sensor heads (M15.5/F40) - fixed in an L-Mount - measuring on the backside of the application specific beam steering mirror. In this example another high-quality mirror is attached to the backside to carry out the interferometric measurement, as this allows highest precision and up to 1° angular motion range (see figure 2).

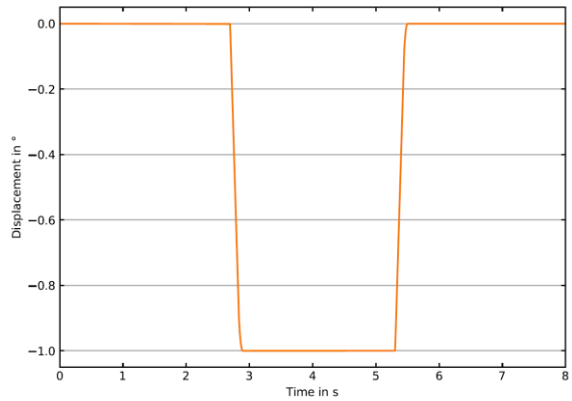

Figure 2: Angular measurement range of each M15.5/F40 sensor head on a highly reflective surface at about 45 mm distance. Rotation created by ECR5050.

It would also be possible to measure directly on lower reflective materials to reduce additional mass, or to attach retroreflectors, which would enable measurement distances of multiple meters and angular motion ranges of up to ± 15°. For a detailed overview of the available sensor heads and the performance on different materials please read Technical Note TN25.

All 3 sensor heads are connected to the same IDS3010 interferometer unit via optical fibers. As each sensor head allows nano precise displacement measurement, the linear x-movement is simultaneously tracked at multiple points. Furthermore, the position of each measurement point is accurately defined by the small mechanical tolerances of the L-Mount and therefore also the pitch and yaw angle can be calculated with nano-degree precision. This leads to an ultra-precise 3 DoF measurement, which detects the actual mirror movement at the Point of Interest (POI) and thereby allows the identification and compensation of e.g. Abbé-Errors. As shown in figure 3 the combination of multiple nano positioning stages inevitably impacts the precision, as the integrated encoder can only detect errors - caused e.g. by thermal expansion - in the specific motion direction of each positioner, but not for the whole stack. Therefore, multiple errors can´t be compensated and sum up, although the integrated encoder offers µ° resolution.

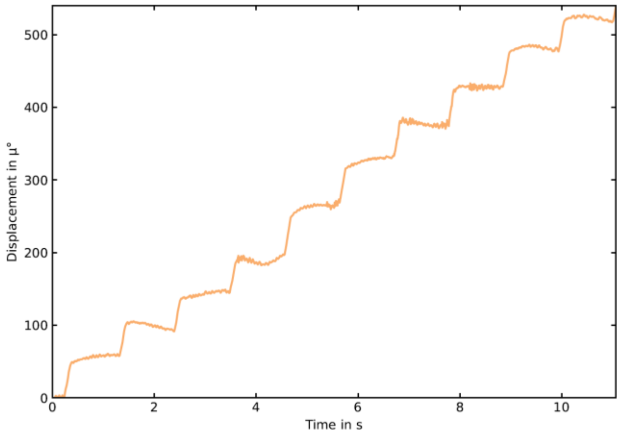

Figure 3: Angular deviations at the Point of Interest (POI) when carrying out 50 µm steps with the ECG5050 in a 3 DoF positioner stack.

The light often travels more than 1 m through the beam steering system before hitting the intended point on the sample or workpiece. Therefore, 10 µ° deviation can already lead to a misalignment of hundreds of nanometer, which is not acceptable for demanding applications. The IDS3010 allows calibration of the mirror alignment system, to increase the accuracy at the POI. With multiple real-time interfaces and a measurement bandwidth of up to 10 MHz it even allows highly dynamic closed-loop motion control, which increases the repeatability significantly.

Laser Vibrometry

The stability of the mirror is crucial to precisely hold the beam at the intended position. Therefore, also the mechanical stability of the utilized alignment optics is essential. Vibrations are one of the biggest challenges for advanced nano-scale applications, as they often require vacuum conditions and therefore pumps located in proximity to the optical setup.

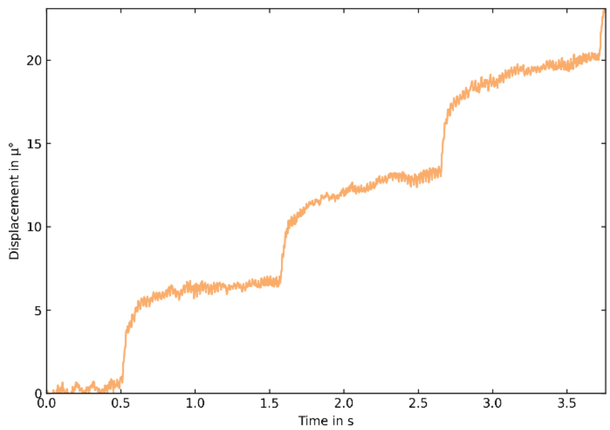

Figure 3: Vibrations causes by post-pulse oscillations leading to significant angular deviations in the 3 DoF positioner setup.

Furthermore, the movement of the 3 DoF nanopositioner stack can cause significant post-pulse oscillations. Figure 3 shows that this can cause angular misalignment of about 1µ°. Analyzing even smallest vibrations is only possible with high bandwidth laser vibrometry, as conventional acceleration sensors don´t offer the required resolution and significantly impact the mechanical properties.

The IDS3010 in combination with the WAVE Vibro software, allows straightforward vibration analysis even in the sub-nm range. Figure 4 shows a FFT analysis of the beam steering mirror.

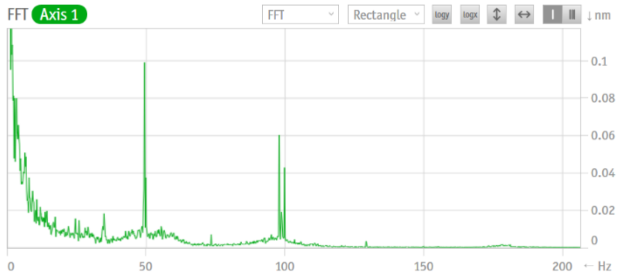

Figure 4: FFT analysis of the beam steering mirror on an optical table without moving the nanopositioners (no post-pulse oscillation)

Conclusion

The modularity of attocube's IDS3010 interferometer enables ultra precise 3 DoF measurements over a large angular range and with a much higher measurement bandwidth than conventional sensors. This allows not only for calibration, but also for closed-loop compensation of occurring angular errors and enables advanced vibrometry to reach the next level of precision in mirror alignment. Furthermore, the fiber-based sensor heads are even compatible with extreme environments, like ultra-high vacuum conditions, and can directly measure on various material surfaces. This outstanding versatility offers a solution to many challenges in a broad field of optical applications.