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Nanometer Precise Positioning During Sample Rotations

Compensation of Rotation Motion Errors with attocube's Interferometric System

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Introduction

Synchrotrons are electron particle accelerators that provide high-brilliance x-ray beams, often used in experiments that study the properties of different materials. Due to the high penetration capabilities and highly focused beams of these x-rays, they are often used in image scans where motion-positioning systems play a primary role.

X-ray nano-imaging requires positioning systems with tight constraints in mechanical construction as well as position metrology [1]. In-axis and crosstalk motion errors, stemming from linear as well as rotational drives, are always present and especially troublesome for scans with nanometer precision. Rotational drives are particularly difficult to characterize in respect to axial runout and wobble [1].

The Nanoprobe project, a four-year collaboration between synchrotron SOLEIL and MAXIV, worked to deliver nanometer-precise scanning tomography prototypes. Over the course of the project, a method to characterize and compensate for rotational motion errors was developed and tested [2,3].

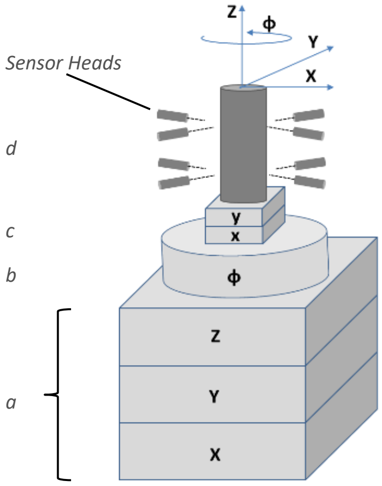

Figure 1: Illustration of the positioners and their respective directions [1,3]. (a) Linear drives for sample positioning in XYZ-space. (b) Φ, rotary piezo driven positioner. (c) XY-axes, piezo driven positioners for sample alignment. (d) Sample holder and interferometry cylinder reflector. Grey lines from sensor heads depict the interferometric beams for sample tracking.

Setup

In addition to being able to fully rotate a sample with µrad resolution, the actuated system had to be capable of nanometer precise positioning over millimeter ranges in three dimensions. For such applications, attocube offers interferometric sensor systems, as for example the IDS3010. Figure 1 and 2 show the overall setup; it consists of a stacked design with nine sensor heads for sample tracking during rotational moves.

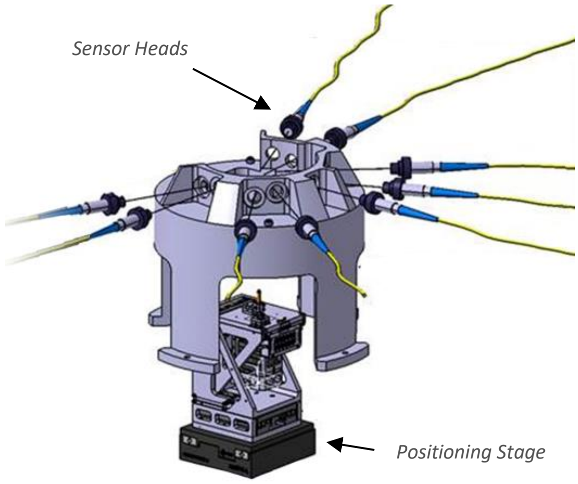

Figure 2: Exploded view drawing of the positioning stage with interferometry sample tracking setup.

For each sample rotation, given well-aligned reflectors and sensor heads, the raw interferometry data was processed, using a multi-probe error separation technique [1]. With Φ denoting the sample rotation around the Z-axis, this process yields:

- Reflector surface errors, $s(\Phi)$.
- XY-runout motion errors, $\varepsilon_x(\Phi)$ and $\varepsilon_y(\Phi)$.
- Wobble, $\Theta_x(\Phi)$ and $\Theta_y(\Phi)$, which is calculated by combining two levels of XY-runout errors.

XY-runout errors of the rotary drive can then be reduced by the two following approaches [1,3].

1. *Position feedforward compensation*

Determining repeatable errors by running the system over several rotations (while simultaneously collecting interferometry data), and correcting for these errors using XY-linear drives.

2. *Interferometric feedback correction*

Using interferometry as feedback (on the sample reflector) in a control loop, actively correcting for repeatable and non-repeatable errors during sample rotations. In case the reflector has surface errors that have been mapped, they can be corrected for in a straightforward manner, coupling it with the interferometric closed loop.

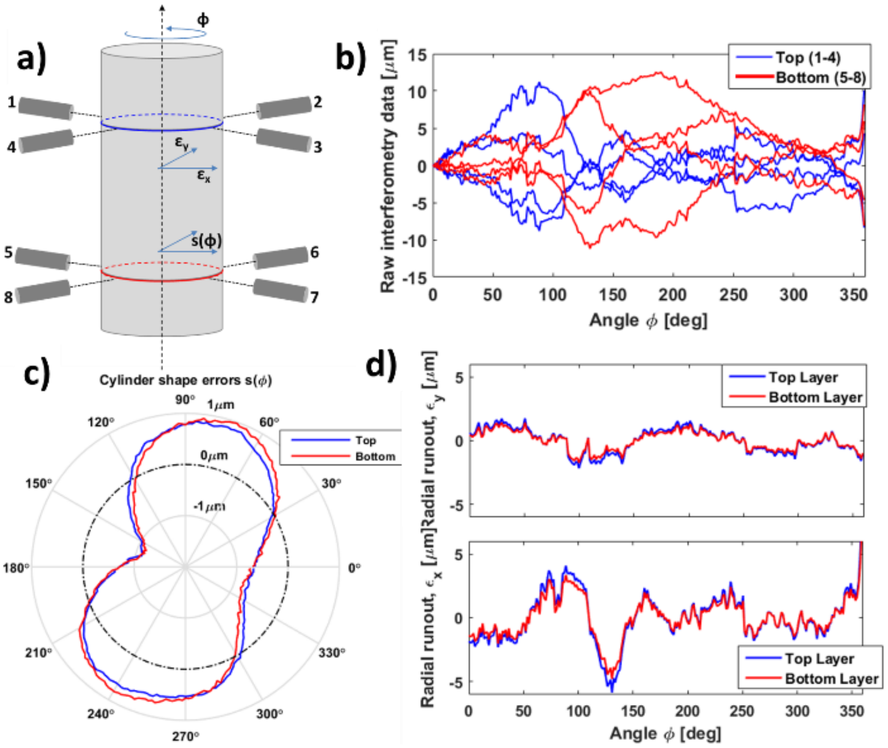

Figure 3: Interferometry measurements and results during a 360° sample rotation in Φ [1]. (a) Schematic view of the interferometry beam alignment on the reflector with two (bottom and top) sets of four sensor heads. (b) Raw interferometry readings from the sample rotation. (c) Result from the error separation, cylinder shape errors s(Φ) (top and bottom). (d) Result from the error separation, top and bottom runout errors ε_x(Φ) and ε_y(Φ).

Measurement Results

Figure 3 shows the results from measuring a full sample rotation. Using the multi-probe error separation algorithm, the raw interferometry data (Figure 3b) was processed to produce the cylinder error shape s(Φ) (Figure 3c) and the XY-runout errors ε_x(Φ) and ε_y(Φ) (Figure 3d) for the two levels [1].

Uncorrected, the XY-runout errors caused by the rotary drive are at a level of ± 1.25 µm, as can be seen in Figure 4. However, by applying the different modes of error correction, one can reduce the errors to ± 170 nm in the case of a feedforward correction (Figure 4b), and to ± 42 nm using active interferometry feedback correction (Figure 4c) while compensating for the reflector surface errors [1,3].

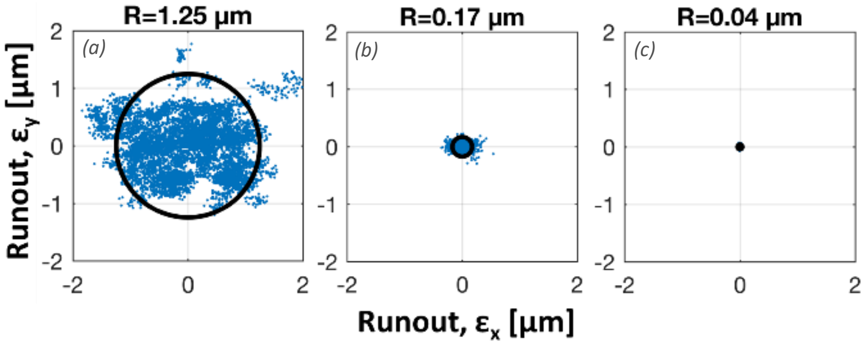

Figure 4: Distribution on XY runout in the top layer during full sample rotations in Φ [1,3]. (a) XY runout without active correction, 90 % circle of confusion was at 1.25 µm. (b) XY runout with active feedforward correction on the repeatable XY-crosstalk errors caused by the rotary drive. 90 % circle of confusion was at 170 nm. (c) XY runout with active XY-interferometry feedback correction on the rotary drive crosstalk position errors ε_x(Φ) and εy(Φ), coupled with feedforward correction on the reflector surface errors s(Φ). 90 % circle of confusion was at 42 nm.

Conclusion

In addition to using high-end linear and rotary drives with advanced modes of control, it is shown that when interferometry is introduced as a tool for rotary drive characterization, associated XY-crosstalk errors can be reduced by as much as 96.7 % (see Figure 5), thus achieving nanometer precise positioning during sample rotations [3].

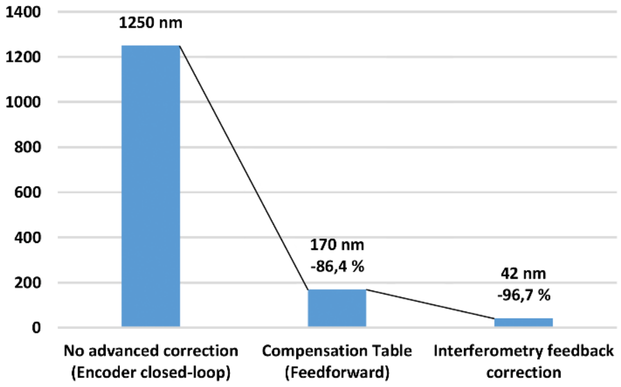

Figure 5: Circle of confusion (90 % of radius in nm) using the different modes of control with attocube's interferometric system.

References

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[2] S. Kubsky, A. Lestrade, N. Jobert, C. Engblom, F. Alves, Method and device for the three-dimensional characterization of a surface of an object, WO Patent App. PCT/EP2015/074,011 (2016).

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