Rotation motion error compensation using interferometry

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Introduction

Synchrotrons are electron particle accelerators that provide high-brilliance x-ray beams for experimental end-stations where it is used to study properties of different materials. These x-rays, having high penetration capabilities and highly focused beams, are often used in image scans where motion positioning systems play a primal role.

X-ray nano-imaging necessitates positioning systems with high constraints in mechanical construction as well as position metrology [1]. In-axis and crosstalk motion errors, from linear as well as rotational drives, are always present and notably troublesome at nanometer-precision scans. 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-precision 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].

Setup

In addition to being able to fully rotate a sample with µrad resolution, the actuated system needed to be capable of nanometer resolute positioning over millimetric ranges in XYZ- space. Figure 1 and 2 show the overall setup; here with a stacked design with nine (attocube FPS 3010) interferometry sensors for sample tracking during rotational moves.

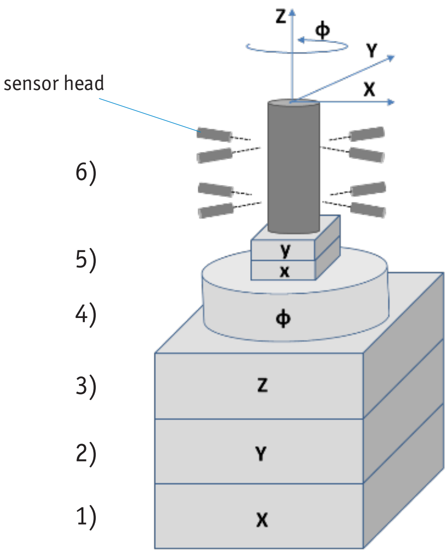

Figure 1: *Schematic diagram illustrating the positioners and their respective directions [1][3].*

(1-3) linear drives for sample positioning in XYZ space. (4) Φ, rotary piezo driven positioner. (5) XY-Axes, piezo driven positioners for sample alignment. (6) Sample holder and interferometry cylinder reflector. Grey lines from sensor heads depict interferometry beams that are used for sample tracking.

For each sample rotation, provided that the reflector and sensors were installed and well aligned, the raw interferometry data could be processed, using a multi- probe error separation technique [1], to provide:

- 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.

where Φ is the sample rotation around the Z-axis.

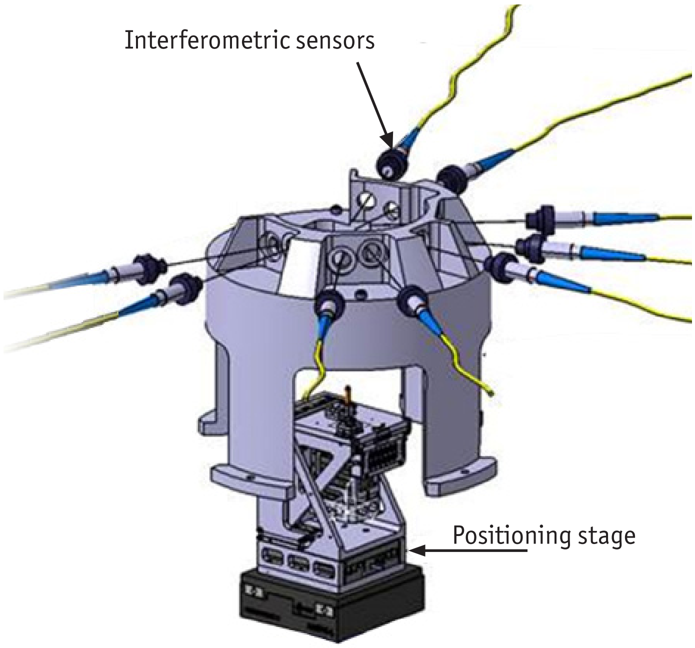

Figure 2: *Exploded mechanical drawing of positioning stage with interferometry sample tracking setup.*

Rotary drive XY-runout errors could then be reduced by two approaches [1][3]:

1. *Position feedforward compensation:*

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

2. *Interferometry feedback correction:*

Using interferometry as feedback (on the sample reflector) in a control loop to actively correct for repeatable and non-repeatable errors during sample rotations. If the reflector has surface errors that have been mapped, they can be corrected for in a feedforward manner coupled with the interferometry closed loop.

Measurement Results

Figure 3 shows the results from a rotation where the raw interferometry data (Fig. 3b) was processed using the multi-probe error separation algorithm to produce: the cylinder error shape s(Φ) (Fig. 3c), and XY- runout errors (Fig. 3d), $\varepsilon_x(\Phi)$ and $\varepsilon_y(\Phi)$, for the two levels [1].

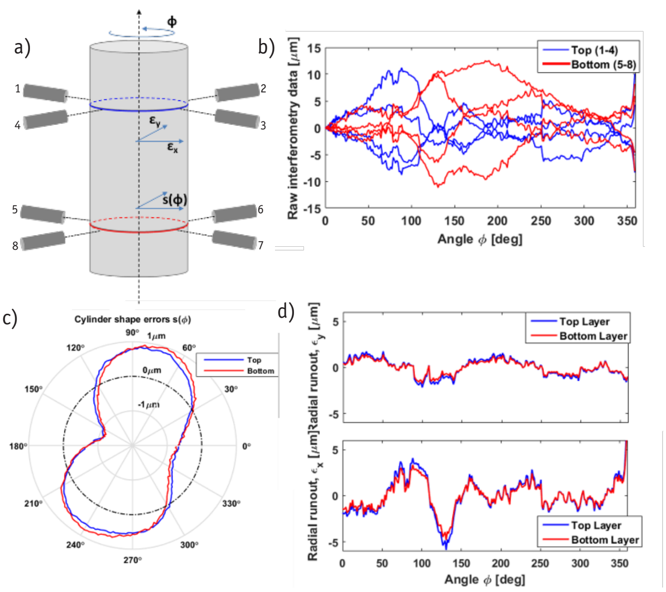

Figure 3: *Interferometry measurements and results during 360 degree sample rotations in Φ [1].*
(a) Schematic view of interferometry beam alignment on the reflector with two (bottom and top) sets of four interferometry measurements.
(b) Raw interferometry readings from 360 degree rotations in Φ.
(c) Result from error separation, cylinder shape errors s(Φ) (top and bottom).
(d) Result from error separation, top and bottom runout errors $\varepsilon_x(\Phi)$ and $\varepsilon_y(\Phi)$.

Uncorrected, one can see that the XY- runout errors caused by the rotary drive are at a level of ± 1.25 µm, as seen in Fig. 4a. By applying the different modes of error corrections however, one can see that the XY-runouts are reduced to: ± 170 nm using feedforward corrections (Fig. 4b), and to ± 42 nm (Fig. 4c) using active interferometry feedback correction while compensating for the reflector surface errors [1][3].

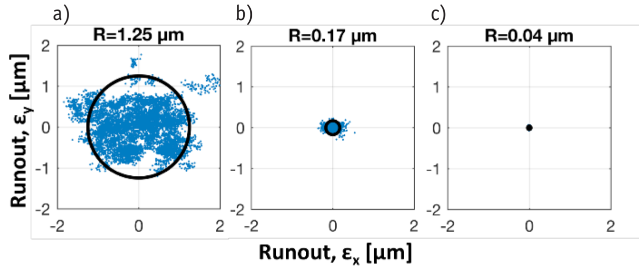

Figure 4: *Distribution on XY runout (ε_x, ε_y) in the top layer during full sample rotations in Φ [1][3].*
(a) XY runout without active correction, 90% circle of confusion was 1.25 µm.
(b) XY runout with active feedforward correction on the repeatable XY- crosstalk errors caused by the rotary drive. 90% circle of confusion was 170 nm.
(c) XY runout with active XY- interferometry feedback correction on the rotary drive crosstalk position errors ε_x and ε_y coupled with feedforward correction on the reflector surface errors s(Φ). 90% circle of confusion was 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, XY-crosstalk errors from the rotary drive can be reduced by as much as 96.7% thus achieving nanometric positioning precision during sample rotations (see Fig. 5) [3].

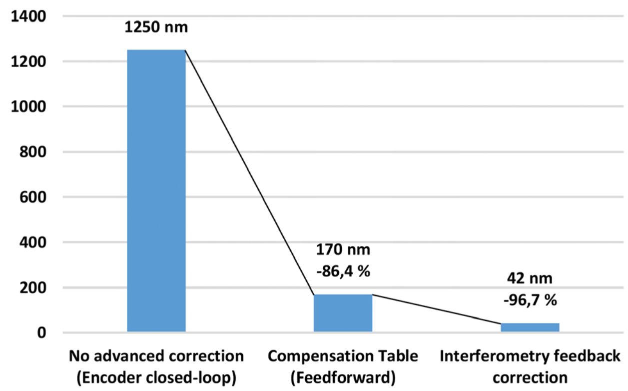

Figure 5: *Circle of confusion (radius of 90% in nm) using the different modes of control with the Attocube FPS-3010 interferometer systems.*

References

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