Instrumentation and measurement techniques for high quality and strongly curved X-ray mirrors at the ESRF metrology laboratory

Amparo VIVO, Benjamin Lantelme, Raymond BARRETT
ESRF, 6 rue Jules Horowitz, BP 220, 38043 Grenoble Cedex 9, France

4th International workshop on Adaptive and Active X-ray and XUV Optics
4-5 April 2011 , Diamond Light Source Ltd, Oxfordshire, UK

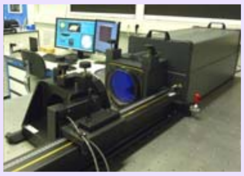
X-ray Optics Group

The ESRF is currently implementing an extensive upgrade of its X-ray source and eight beamlines. Reaching the target performance of the new experimental stations requires X-ray optical elements of exceptional quality. Particular challenges are to deliver optics with the extremely low slope and shape errors capable of exploiting improvements in the source emittance for applications such as ultra-high energy resolution inelastic scattering, coherent scattering and nanofocusing.

Surface optical metrology plays a key role not only for the quality control, but also in improving the manufacturing processes of such components. The highly aspheric surfaces for large numerical-aperture nano-focusing KB systems will typically require measurement of shape errors in the nm range.

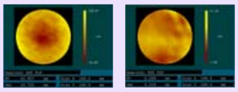
Metrology Lab recent upgrade

Phase-shifting Fizeau Interferometer : Zygo VeriFIRE AT+ 150mm aperture



- Acquired Nov. 2009 – replaced agingWyko 6000
- High resolution camera (1k x 1k)
- Encoded zoom
- Selection of transmission and reflection optics
  150 mm TF λ/40, 100 mm TS f/3.3 λ/50,
  150 mm TF λ/20 for high reflectivity optics,
  150 mm RF

Repeatability on 2 successive measurements: 0.2 nm rms
Rms deviation over 10 successive measurements = 0.03 nm



- **New capabilities**
  - Powerful software – automated measurements
  - Artefact suppression (e.g. dust particles)
  - Accurate sphere radius measurement (up to Rs =1 m)
  - Measurement of short radius mirrors (R > 15 m) with TF optic

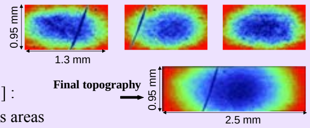
Phase-shifting Micro-interferometer: modified Veeco NT9300

- Mid-Spatial-Frequency Roughness (~ mm^{-1} – µm^{-1})
- Acquired December 2008: replaces Micromap 512
- Custom adapted for surface roughness measurements of large (1 m long) X-ray mirrors
- Dual-LED source: white (VSI) or green (PSI) light
- Fully motorised X-Y (±150 mm), Z and tip-tilt stages
- Objectives: 2.5x, 5x, 50x, 5x LWD

Repeatability: 5 picometers rms
Noise level: 19 picometers

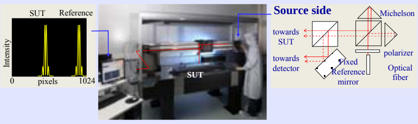
- **New capabilities**
  - Powerful software – automated measurements
  - Accurate repositioning of samples
  - Automated measurement sequences
  - Sub-aperture stitching of overlapping fields [1-2-3] : surface roughness evaluation over large contiguous areas

Micro-stitching example: 3 sub-maps 50% overlapped (5x)

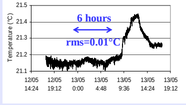


LTP: stability, RoC reproducibility, stitching

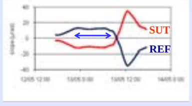
LTP signal Stability



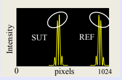
Temperature over 24h

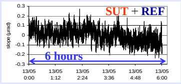


SUT and REF stability (24h)



Temperature changes induce asymmetry of fringe pattern





Efficient drift correction by adding both signals
⇒ noise ≈ 0.08µrad

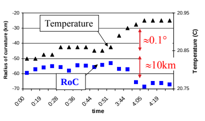
Repeatability improved by:

- **Reference correction**
- **Fast scans (40mm/sec)**
- **Averaging scans**

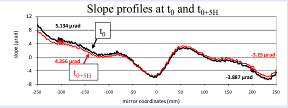
Long RoC measurement reproducibility

LTP measurements at unequal intervals during 5 hours of a 700 mm long Si mirror, 40 mm thick, supported by 3 balls at Bessel points
Convex RoC ≈ 55 km

Obvious correlation between Temperature and RoC drift

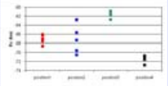


Drift affects only RoC results, not slope error profiles



slope errors:
rms_{t0} = 2.42 µrad
rms_{t0+5H}=2.40 µrad

RoC obtained at different positions of the mirror under LTP translation give different values (mechanical holder repositioning, temperature,…)



Measuring accurately long radius of curvature with LTP is not an easy task !!

A Round-Robin campaign would be useful…

LTP Stitching procedure

Accurate LTP measurements of strongly curved mirrors of high quality is not possible if systematic errors are not corrected.

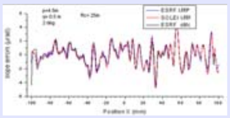
Our approach is to measure curved mirrors by stitching short LTP scans as a succession of nearly flat mirrors.

The length of each scan is defined by keeping a constant angular deviation and allowing a minimum overlap of 3mm for each consecutive scan.

The mirror is tilted between each scan position to reproduce a similar path of the reflected beam over LTP optical elements.

The final mirror slope profile is obtained by stitching the scans together and overlapped areas are averaged. The procedure has been **fully automated** to limit environmental perturbations between each individual scan and significantly reduce the measurement time.

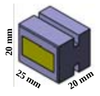
ESRF LTP stitching technique compared to the so-called LEEP [4] (linearity error elimination procedure) measurement procedure developed at the SOLEIL synchrotron.



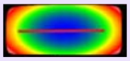
LTP-ZYGO-VEECO shape error profile comparison

Silicon sphere for KB mirror

Manufacturing specifications
R=19.0 ± 0.5 m
λ/10 Power and tilt removed
micro-roughness < 0.1 nm rms



Measurement and analysis parameters

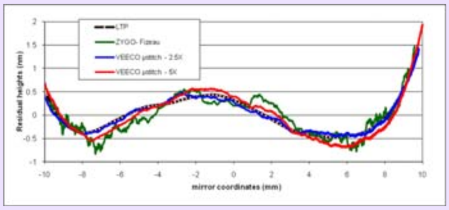
LTP	ZYGO	VEECO
Stitching procedure 10 sub apertures, 3 mm overlapped , sampling 0.2mm scan A to B averaged with scan after 180° mirror rotation (B to A) Analysis : **1D slope integrated to get height profile** 	Reduced cavity – average of 10 acquisitions for initial mirror position and after 180° flipping - Average of both results Analysis: **1D height profile averaged 2mm in sagittal direction**  25 mm x 20 mm	**2.5x :**2.5mm x 1.9mm 19 sub maps/ 20 mm **5x :**1.3mm x 0.95mm 38 sub maps/ 20 mm Average 20 - 50% overlap Analysis: **1D height profile averaged 250µm in sagittal direction**  20 mm x 1.9 mm 20 mm x 0.95 mm

Results

Instrument	LTP	ZYGO	VEECO 2.5X	VEECO 5X
Lateral resolution	2 mm	30 µm	4 µm	2 µm
RoC	19.487 m	19.687 m	19.105 m	18.982 m
Shape error RMS	0.36 nm	0.40 nm	0.35 nm	0.44 nm
Shape error PV	1.81 nm	2.30 nm	1.90 nm	2.19 nm

Radii of curvature differ in a range of 0.7 m.

Shape error profile agreement is better than 0.5 nm peak to peak.



1. A.Rommeveaux, R. Barrett, “Micro-stitching interferometry at the ESRF” Nuclear Instruments and Methods in Physics Research Section A, Volume 616, Issues 2-3, 1 May 2010, Pages 183-187
2. L. Assoufid, J. Qian, C. M. Kewish, C. Liu, R Conley, A.T. Macrander, D. Lindley, C. Saxer, “A microstitching interferometer for evaluating the surface profile of precisely figured x-ray K-B mirrors”, Proc. SPIE, Vol. 6704, 670406 (2007)
3. K. Yamauchi, K. Yamamura, H. Mimura, Y. Sano, A. Saito, K. Ueno, K. Endo, A. Souvorov, M. Yabashi, K. Tamasaku, T. Ishikawa, Y. Mori,” Microstitching interferometry for x-ray reflective optics”, Rev. Sci. Instrum. 74, 2894 (2003)
4. F. Polack, M. Thomasset, S. Brochet, A. Rommeveaux, “An LTP stitching procedure with compensation of instrument errors: Comparison of SOLEIL and ESRF results on strongly curved mirrors”, Nuclear Instruments and Methods in Physics Research Section A, Volume 616, Issues 2-3, 1 May 2010, Pages 207-211

The research leading to these results has received funding from the European Community Seventh Framework Program (FP7/2007-2013) under Grant agreement no. 226716.