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The COST P7 Round Robin for Slope Measuring Profilers

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Abstract. As part of the COST P7 Action, the metrology facilities of four European synchrotrons – Bessy, Elettra, ESRF and Soleil – instigated a round-robin programme of instrument inter-comparison. Other synchrotrons will later join this programme. The metrology instruments involved are various direct slope measurement devices, such as the well known Long Trace Profiler (either custom built or modified from commercial devices) and the Bessy Nanometer Optical component measuring Machine (NOM). The round robin was realized by measuring two flat and three spherical mirrors (made of either Zerodur or fused silica) made available by Bessy, Elettra and Soleil. The programme has been a significant aid in the characterization of each of the instruments and could readily be extended to other devices as a calibration tool. The results and advantages are described in this chapter.

14.1 Introduction

Most of the synchrotron radiation (SR) sources have developed their own metrology laboratory to meet the need of optics characterization in terms of microroughness, radius of curvature, slope errors, and shape errors. The instrumentation used consists mainly of commercial instruments: phase shift interferometers for microroughness characterization or Fizeau interferometers for bidimensional topography and optical profilometers for measurements of long optical components like the long trace profiler (LTP) or the nanometer optical component measuring machine (NOM). The LTP was developed at the Brookhaven National Laboratories by Takacs et al. [1], and marketed by Continental Optical Corporation (now Ocean Optics). It is basically a double pencil slope-measuring interferometer, for determining the slope error and radius of curvature and, through integration, the height profile for optical surfaces larger than 1 m in length. Optimally, precise data can be obtained, with reproducibility on the order of 2 nm $P{-}V$ (or 0.1 μrad RMS). What, however, is about the absolute precision of these profilometers? This is directly linked to instrument calibration, and up to now there is no standardization of calibration. In this round-robin endeavor, typical X-ray mirrors provided by the laboratories, plane, spherical, or toroidal are examined by the several laboratories using their own instrumentation in order to better understand the accuracy achievable with them.

The ultimate goal of this Round Robin is to create a database of the measurement results in order to provide these references as calibration tools available for metrology community.

14.2 Round-Robin Mirrors Description and Measurement Setup

Five mirrors have been involved in the present Round-Robin, two plane and three spherical, with varied parameters: reflectivity, material, radius of curvature, dimensions. Their main characteristics are given in Table 14.1.

The mirrors were measured with their optical surface up or on the side according to the standard instrument setup of each laboratory. To limit mechanical stress (sag) due to gravity in case of mirror facing up, the measurement procedure consisted in supporting the mirror with three balls placed at the Bessel points. The trace centered on the optical surface is perfectly defined on each mirror by lateral marks as well as is the scan direction. Each laboratory was free to define the appropriate number of scans to achieve the best accuracy of its instrument. Measurement procedures and parameters are summarized in Table 14.2.

14.3 Measurement Results

For each mirror, the resulting data consist in an array of mirror coordinates and corresponding measured slope. The same calculation method has been applied to process all these data in order to avoid discrepancies due to differences in fitting or integration methods. Slope errors and shape errors correspond to residual slopes and heights after best sphere subtraction. For plane mirrors (Table 14.3) there are important differences on radii values, but it is important to underline that each laboratory obtains a good repeatability of its value. The radius of curvature is obtained from the mirror slope profile. Obviously for plane mirrors with very large radius, the slope linear trend is affected by the intermediate frequencies measured. For this reason the radii results are not in a good agreement.

The graphical results (Fig. 14.1) for mirror P1 show an impressive consistency between residual slopes measured by each laboratory.

For spherical mirrors, the slope variation over the mirror length is obviously greater, implying a stronger influence of the individual characteristics of the different instruments on the measurement results. For LTPs, systematic errors can be corrected by averaging several measurements using different area

Table 14.1. Characteristics of the mirrors tested

Label	P1	P2	S1	S2	S3
Owner	BESSY	Elettra	Elettra	BESSY	Soleil
Dimensions $L \times W \times H$ (mm^3)	$310 \times 30 \times 60$	$400 \times 60 \times 80$	$270 \times 40 \times 30$	$210 \times 40 \times 40$	$120 \times 20 \times 50$
Bulk material	Zerodur	Zerodur	Fused silica	Zerodur	Silicon
Coating	none	Gold	Gold	None	None
Shape	Plane	Plane	Spherical $R = 83$ m	Spherical $R = 44$ m	Spherical $R = 1{,}280$ m
Residual slope error rms	≈1.1 μrad	≈0.7 μrad	≈1 μrad	≈1 μrad	≈0.5 μrad
Scan length	290	390	240	198	110

Table 14.2. Measurement parameters and scanning conditions

	BESSY	ELETTRA	ESRF	SOLEIL
Instrument	Autocollimator	LTP	LTP	LTP
Mirror position	Face up	On the side	Face up	Face up
Number of scans averaged	10	6 with mirror tilt	4	1
Systematic errors correction	Not applied	By mirror rotation	By mirror rotation	Not applied
Scanning method	Point by point	Point by point	On fly	On fly over sampling
Scanning velocity	1 mm s^{-1}	1 mm s^{-1}	40 mm s^{-1}	0.2 mm s^{-1}

Table 14.3. Statistical results obtained for P1 and P2 mirror

	P1 mirror			P2 mirror		
	R (km)	Slope error rms (μrad)	Height error rms (nm)	R (km)	Slope error rms (μrad)	Height error rms (nm)
BESSY	427	1.16	24	−1,951	0.88	24
ELETTRA	454	1.12	23	753	0.81	19
ESRF	136	1.12	24	242	0.97	28
SOLEIL	193	0.88	17	−100	1.64	52

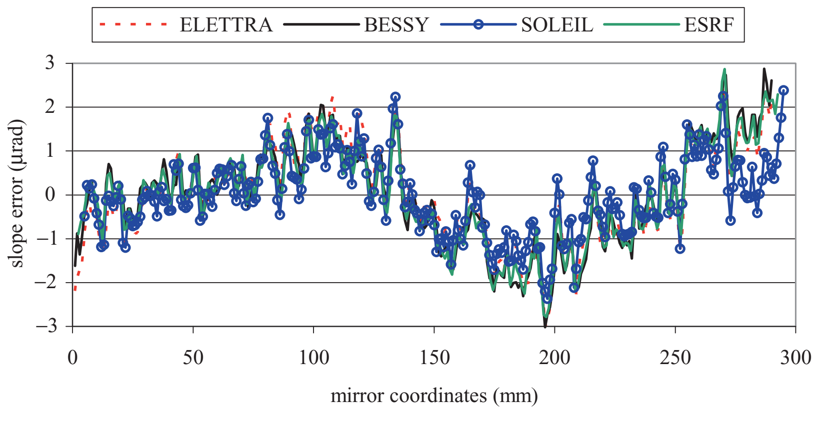

Fig. 14.1. P1 residual slopes after best sphere subtraction

in the internal optics. Table 14.4 shows the statistical results obtained for the three spherical mirrors.

The values for radius of curvature is in agreement by better than 0.3%. The concordance of residual errors is better for S3, which has the shortest length and the longest radius, than for S2 which has the opposite features. The rms agreement of the slope errors varies from 0.13 µrad (1.6 nm) for S3 to 0.26 µrad (4.1 nm) for S2. A gain, the residual slope profiles obtained at each facility are in excellent agreement in particular between BESSY, using the autocollimator sensor of the NOM, and LTP at the ESRF (Figs. 14.2–14.4).

Table 14.4. Statistical results obtained for S1, S2, and S3 spherical mirrors

	S3			S1			S2		
	R (m)	Slope error rms (µrad)	Height error rms (nm)	R (m)	Slope error rms (µrad)	Height error rms (nm)	R (m)	Slope error rms (µrad)	Height error rms (nm)
BESSY	1,280	0.44	3.2	83.01	0.87	11.7	44.52	1.08	17.4
Elettra	1,274	0.53	4.6	83.21	1.05	15.4	44.67	0.86	13.3
ESRF	1,278	0.40	3.0	83.34	0.99	15	44.76	0.82	13.3
Soleil	1,272	0.51	2.8	83.11	0.92	12.7	44.63	1.41	20.3

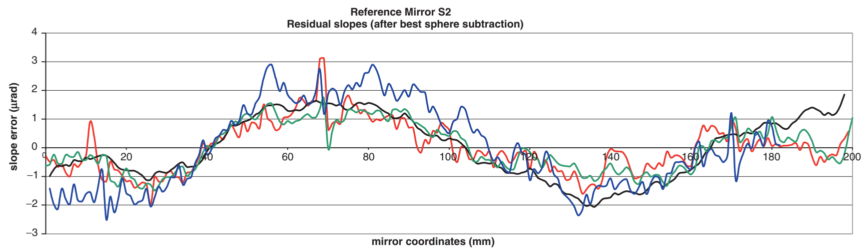

Fig. 14.2. S3 ($R \approx 1.3$ km) residual slopes after best sphere subtraction

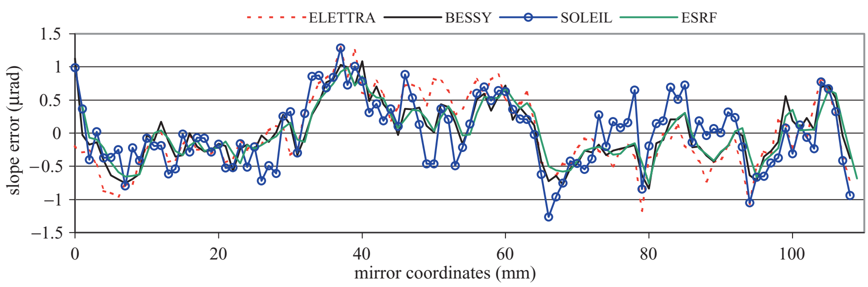

Fig. 14.3. S1 ($R \approx 83$ m) residual slopes after best sphere subtraction

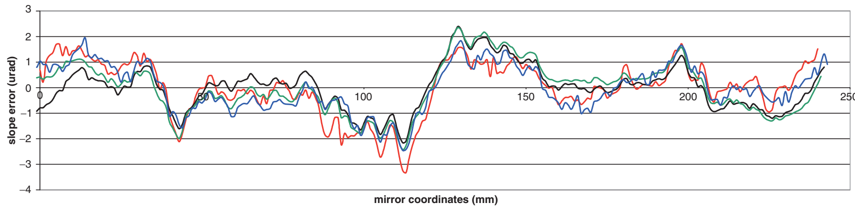

Fig. 14.4. S2 ($R \approx 44\,\mathrm{m}$) residual slopes after best sphere subtraction

14.4 Conclusions

The five mirrors involved in this Round-Robin are good representatives of the kinds of SR optical components to be characterized by slope measuring instruments. These results are in very good agreement with each other, despite the fact that different instruments have been used, in terms of optical setup, hardware, and environmental conditions. Even for the spherical mirrors with a short radius of curvature, which push the measurement accuracy of the instruments to their respective limit, due to the quality of their optical components (mirrors, prisms, lenses), the radii determined agreed better than 0.3%. The curves of the residual slopes after best sphere subtraction are quite superimposable.

These five mirrors cross measured with high consistency can be considered as reference mirrors for instrument calibration. The round-robin is going to be continued, including additional facilities and increasing the number of reference mirrors to be tested [2].

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