Global High-Accuracy Intercomparison of Slope Measuring Instruments

Frank Siewert[1]*, Lahsen Assoufid[2], Daniele Cocco[3], Olivier Hignette[4], Steve Irick[5], Heiner Lammert[1], Wayne McKinney[5], Haruhiko Ohashi[6], Francois Polack[7], Shinan Qian[8], Seungyu Rah[9], Amparo Rommeveaux[4], Veit Schönherr[10], Giovani Sostero[3], Peter Takacs[8], Muriel Thomasset[7], Kazuto Yamauchi[11], Valeriy Yashchuk[5], Thomas Zeschke[1]

[1]BESSY mbH, Albert-Einstein-Straße 15, 12489 Berlin, Germany,
[2]APS, Argone National Laboratory, 9700 South Cass Avenue, Argone 60439,IL, USA,
[3]Elettra, Sinchrotrone Trieste, SS14 Km163.5 in Area Science Park, 34012 Trieste, Italy,,
[4] European Synchrotron Radiation Facility, ESRF, 6 rue Jules Horowitz, BP 220 . 38043 Grenoble Cedex, France,
[5]ALS, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley CA 94720-8199, USA,
[6]SPring-8/JASRI, 1-1-1 Kouto, Mikazuki-cho, Sayo-gun, Hyogo 679-5198, Japan,
[7]Synchrotron Soleil, BP 34 - Saint Aubin, 91192 Gif sur Yvette, France,
[8]BNL, Brookhaven National Laboratory, Upton, NY 11973, USA,
[9] Pohang Accelerator Laboratory/POSTECH, Hyoja-Dong San 31, Namku, Pohang, 790-390, Rep. of Korea
[10]SLS, WSLA 119, Paul Scherrer Institut, CH-5232Villingen, Switzerland,
[11]Departement of Precision Science and Technology, Graduated School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka, 565-0871, Japan

Abstract. The upcoming generation of high accuracy synchrotron radiation (SR) optics will be characterized by a slope deviation from ideal shape in the range of some 0.05µrad rms at a sampling interval of about 1mm. To certify and improve the measurement capabilities of metrology tools to inspect these stringent specifications, an essential step is a worldwide intercomparison of these measurements based on a set of transfer standards. It is the aim of these cross measurements to verify the "absolute" correctness and comparability of the measurement results obtained by the cooperating partners when measuring the topography of specific reference optics (ROs) using their latest metrology tools and methods. Organized by members of the SR-optics community, new national and international cross measurement comparisons of typical synchrotron radiation mirrors have been realized during the last few years: A round robin test by the European COST-program (BESSY, Elettra, ESRF, Soleil) during the years 2004-2005 and a similar cooperation realized by the APS, ESRF and Spring-8 have proceeded. The first results of both projects were presented at the "Optics & Photonics" conference in San Diego in August 2005 [1, 3]. This work build upon earlier work [2, 4]. The participants of both groups and representatives of other SR-laboratories agreed to start a global cooperation bringing together the two round-robin projects and open these activities to other partners from the SR-community, optical manufacturers and other interested parties. This initiative is intended to start an extensive comparison of various measurement principles and tools and will help to push the frontiers in metrology, and hence production, to a precision well below the current state-of-the-art limit of 0.5µrad rms for slope errors.

Keywords: X-ray optics, metrology, Deflectometrie, LTP, NOM, Round Robin, Synchrotron Radiation.
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INTRODUCTION

Organized by members of the X-ray optics community a number of national [1, 2, 3, 4] and international cross measurement comparisons have been realized during the last years. A round robin initialized by the European COST-program (Cooperation on Science and Technology) joining BESSY, Elettra, ESRF, and Soleil during the

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years 2004-2005 and additionally at the same time a cooperation realized by the APS, ESRF and Spring-8 have proceeded [1, 3]. The first results of both projects were presented at the "Optics & Photonics" conference in San Diego in August 2005. During the San Diego meeting the participants of both groups and the representatives of further SR-Laboratories agreed to start a global joint cooperation bringing together the two round robin projects and open these activities to other interested partners.

AIM OF THE INTERCOMPARISON

The aim of these cross measurements is to verify the correctness and comparability of the measurement results obtained by the cooperating partners when measuring the topography of specific references using measuring instruments of the highest accuracy available today.

ORGANIZATION AND PARTICIPANTS

The Organizer of the intercomparison is the international community of metrology scientists working on the field of X-ray optics at different SR labs in the world. The organizing committee is represented by Lahsen Assoufid (APS), Frank Siewert (BESSY), Peter Takacs (BNL), Daniele Cocco (Elettra), Seungyu Rah (PLS) and Haruhiko Ohashi (SPring-8). An invitation to participate is announced with help of the X-ray optics listserver mailer: (xrayoptics-l@lists.bnl.gov) under administration of Peter Takacs (BNL). Participants in the comparison may be laboratories of any purpose (synchrotron labs or other research institutes, national standard institutes or test laboratories of industry), which operate a high-precision topography measurement facility.

HANDLING

The round robin will be performed as a ring-type comparison. It is preferred that, after the measurement, the participant ship the reference optics to the next participant. This should be realized in close consultation with the owner of the reference to keep them informed regarding the actual fate and state of the reference. The reference has to be transported by a trustworthy parcel service or by the participant himself and must be covered by insurance. The participating laboratory is responsible for the undamaged state of the reference until it is shipped to the next partner. The surfaces of the reference optics are only allowed to be cleaned after the allowance is given by the owner. In principle, it is not allowed to touch or otherwise contaminate any part of the reference optic and especially the optical surface.

MEASUREMENT PROGRAM

Reference Optics

The reference optics are high-quality optical elements primarily manufactured to be used in SR beamlines. The Substrate material is in most cases single-crystal silicon or Zerodur©. A reference made of ULE© would be welcome. Each RO is to be marked by two points on the two front ends of the substrate to define the line of inspection. The starting point x=0 is to be marked to define the scan direction. The starting position should be defined by specifying its distance relative to the edge of the mirror. For each reference the section of inspection is to be defined by the distance of the first measuring point to x=0 and the scan length.

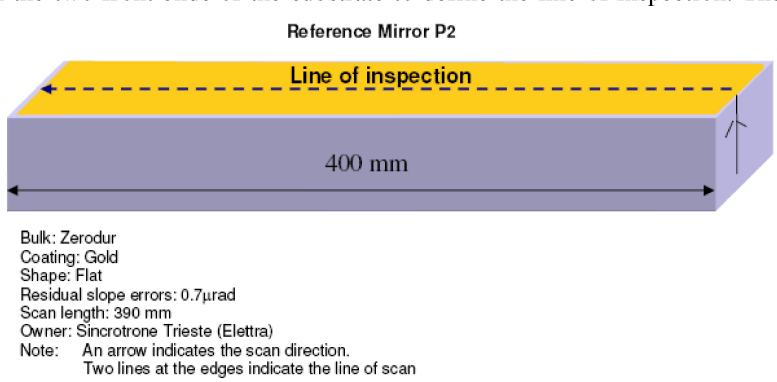

FIGURE 1.
Drawing and description of mirror P2, used for cross measurements in the COST round robin

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A drawing of the mirror, with all the information necessary to perform the scan in the proper direction and starting from the proper point will be prepared for each mirror, as was made for the COST round robin (see Fig. 1). At the moment eleven plane, spherical and toroidal mirrors are available to be used as reference optics.

Intercomparison Procedure

It is proposed here that line scans be the accepted measurement form for intercomparison. Additional measurement forms can give the results of surface mapping data as a second option and is, if possible, especially highly welcome. It is up to the participant to measure both line scans and the complete topography. Additional options to compare the instruments used in this project can be set up by agreement of the concerned participants. The additional activities should be defined in an endorsement paper.

Adjustment of the Reference Optic

The adjustment of the RO should render the optical surface normal upward. The RO is to be supported by three steel or ceramics balls at the Bessel points (22.32 % of sample length from the edges of the reference). The owner of the mirror should mark very clear the three supporting points on the back of the mirror. If possible, a mounting plate with machined and hardened steel cone-vee-flat mounting points should be shipped together with the RO.
The sample should be measured face up. If this is impossible (e.g., in the case of a measurement on an interferometer), a variation of the sample adjustment is to be noted in the data file header.

Upon Receipt of the Reference Optic

It is highly recommended that the rr-participant take photographs (preferably high resolution digital) of the delivered package before opening, and also of the inner packaging, in case of suspected rough handling during transit. Photographs of the RO after it has been mounted are also recommended for any instruments that are used for the report.

Measurement Condition – Monitoring of Environmental Conditions

The physical stability of the sample and the measuring instrument are essential to guarantee the environmental conditions required for highly accurate measuring results. A 24h waiting time after adjustment is recommended before the first inspection of the test surface. For a better comparison of the measurement results it is essential to know the environmental conditions during the measurement. It is proposed to note (or even better to continuously record) the temperature during the measurement close to the RO. Other important aspects of environmental stability should be recorded also. To characterize and compare the instruments used, a 15 hour minimum stability scan with room temperature curve is requested. This file should be provided once per instrument.

Calibration

Each participating laboratory is allowed to use its in-house developed technique of calibration and or autocalibration. A description of the used calibration method should be given by the participating lab. At least it is essential that this round robin is a comparison of the measuring results achieved by use of the different standard measuring procedures used at different labs.

Measurement Data

The measurement results of the participants are to be sent to all participants of the round robin project just after the measurement. Each laboratory has to provide “the measure” according to its usual procedure plus 10 scans made along the same line (to estimate the repeatability and the environmentally induced error) plus at least 5 but possibly 10 scans made under different alignment conditions (i.e., tilt of the reference) to estimate the systematic errors. The two sets of data will be used to calculate the error bars of the provided measurement results. The data files should consist of a header (of 40 lines) and the measuring data it self, noted in two columns in the case of a line scan (first for sample position x [mm], second for slope value s [urad] or height value h [nm]). In case of a 2d-map, the file

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contains three columns (first for sample position x [mm], second for sample position y [mm] perpendicular to x, third for height [nm]). For each measurement, the starting point x=0 (line scan) or x=0; y=0 (2d-map) is to be noted. This is a very simple option to describe the data format but at least it can be converted easily to any other kind of data format. An easy way to name the files is suggested. For instance, MX_LAB_av.dat; MX_LAB_01.dat; MX_LAB_a.dat, where MX mean mirror number X (according to a well defined table), LAB is the laboratory name (or acronym) _av is the given file , _01 _02.. are the 10 scans on the same alignment and _a, _b, _c .... are the different alignment results. The header of the data file must include a description of the measuring method, the procedure applied, step width of the measurement, temperature at sample and laboratory and other significant measuring parameters. It is possible to use different techniques of calibration and autocalibration.

Data Analysis

For comparison of the results, the discrete data points will be fitted by use of the same type of interpretive code to ensure comparability of the data recorded at different coordinates. The data to be analyzed are without taking off any kind of polynomial or smoothing. Only "absolute" measured data are taken for the comparison. In the case of a sphere, the residual shape error is to be compared by fitting the same value for the radius of curvature to the data. Radii have to be calculated based on slope data.The random error of the measurement is to be expressed by the uncertainty band or by an error bar. The error bars are not an expression for the measurement uncertainty achieved. It only describes the repeatability and the random error of the system. The measurement uncertainty describing the systematic and random part of the error budget is to be estimated for each measurement result specifically. For the comparison of 2d-measurements, the use of Zernike polynomials is possible.

COST OF THE CROSS MEASUREMENTS

Each participant will bear the costs incurred by the project at his laboratory. The costs arising for the transport are to be financed by the forwarder.

TIME SCHEDULE

This is a work in progress. First results have been presented at the "3rd International Workshop on Metrology for X-Ray Optics",. May 27./28.th, 2005 in Daegu / Korea.

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