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Nano-accuracy measurements and the surface profiler by use of Monolithic Hollow Penta-Prism for precision mirror testing

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ABSTRACT

We developed a Monolithic Hollow Penta-Prism Long Trace Profiler-NOM (MHPP-LTP-NOM) to attain nano-accuracy in testing plane- and near-plane-mirrors. A new developed Monolithic Hollow Penta-Prism (MHPP) combined with the advantages of PPLTP and autocollimator ELCOMAT of the Nano-Optic-Measuring Machine (NOM) is used to enhance the accuracy and stability of our measurements.

Our precise system-alignment method by using a newly developed CCD position-monitor system (PMS) assured significant thermal stability and, along with our optimized noise-reduction analytic method, ensured nano-accuracy measurements. Herein we report our tests results; all errors are about 60 nrad rms or less in tests of plane- and near-plane- mirrors.

1. Introduction

Having measurements with nanometer- and nano-radian-accuracy (nano-accuracy) is extraordinarily important for the National Synchrotron Light Source II (NSLS II) of Brookhaven National Laboratory (BNL). A Long Trace Profiler (LTP) system, applying scanning optical head for sampling and reference beam for compensation of slide pitch error, was developed at BNL in 1989 [1,2]. The penta-prism LTP (PPLTP), applying the scanning penta-prism to eliminate the impact of an air-bearing pitch error [3], was developed at ELETTRA, Italy, in 1995. The LTP, PPLTP and other developed profilers faced high demands for improved accuracy. For this purpose, the Nano-Optic-Measuring Machine (NOM) was developed for the third-generation storage ring, at Helmholtz-Zentrum Berlin für Materialien und Energie GmbH (HZB)/BESSY-II, Germany, in 2003 [4]. The NOM is a high-accuracy instrument with 50 nrad precision or better, for measuring the surface profiles of large mirror surfaces [5]. The strategy for BNL's optical-metrology laboratory is first to devise a test with nano-accuracy for plane- and near-plane-mirrors, and then to obtain detailed measurements of strong curved surfaces. In recent years, many synchrotron-optics metrology laboratories built their own improved NOM systems so to attain nano-accuracy in testing plane- or near-plane mirrors [6–10]. The NSLS II has designed two new Monolithic Hollow Penta-Prism Long Trace Profiler NOMs (MHPP-LTP-NOMs) that include MHPP-LTP-NOM1 (Fig. 1, one axis, 1 m travel), and MHPP-LTP-NOM2 (Fig. 2, two-axes, 1.5 m for the X axis, and 0.3 m for the Y axis). The two instruments use the same autocollimator, precise air-bearing system and control-measurement software in EPICS. The MHPP-LTP-NOM2 also is combined with a Shack–Hartmann optical head to test 2-D curved mirrors [11]. Another reason for developing the MHPP-LTP-NOM was to use it as a comparison and calibration-device for developing our new Nano-accuracy Surface Profiler (NSP) to test highly curved mirrors with nano-accuracy [12].

The MHPP-LTP-NOM includes the following equipments:

- newly developed precision Monolithic Hollow Penta-Prism (MHPP);
- high-accuracy autocollimator ELCOMAT 3000 as the angle-monitoring optical head;
- precision air-bearing system made by Q-Sys company with pitch–yaw errors < 10 urad P–V (Fig. 3);
- two adjustable mirror support units.

Herein, we detail its development and research on how we attained nano-accuracy measurements. Already, it has demonstrated about 60 nrad rms repeatability, so exceeding the demanded designing accuracy of < 100 nrad rms. Its accuracy could be considered similar to repeatability in the cases of testing plane- or near-plane-mirrors, with very good beam alignment and careful measurement technology, because there is almost no beam lateral motion (BLM) during the measurements. The BLM is the lateral optical-path displacement of sample or reference beam that happens when it is tested on a curved mirror or when the beam is not

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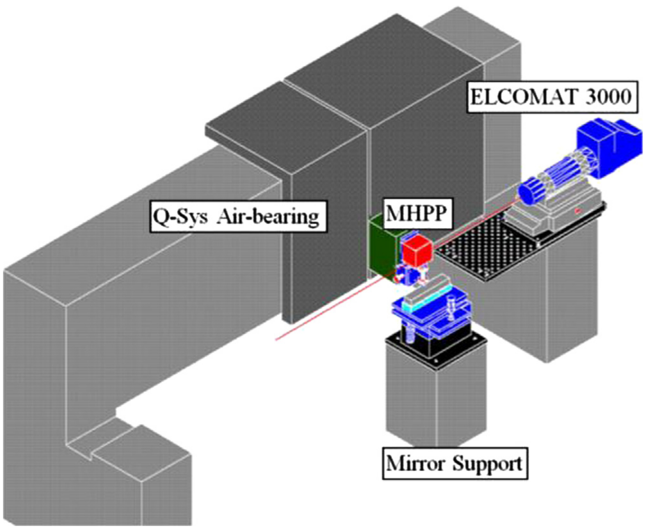

Fig. 1. MHPP-LTP-NOM1: 1 axes, 1 m travel, for research and development, calibration of NOM/NSP.

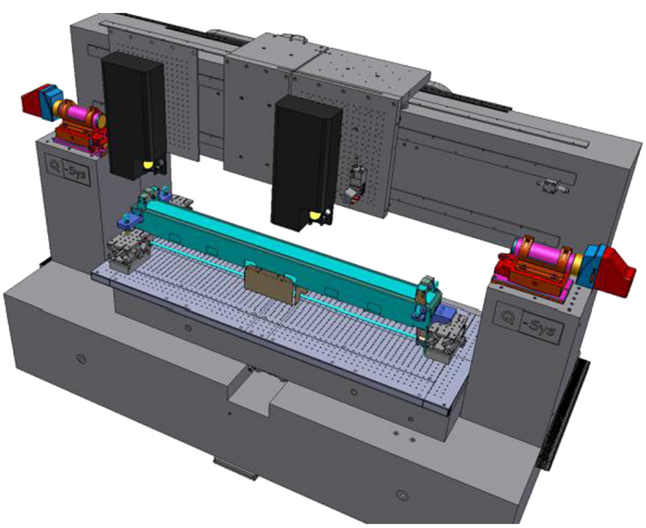

Fig. 2. MHPP-LTP-NOM2: Combined with a Shack–Hartmann stitching interferometer, 2 axes, travel 1.5 m for X axis and 0.3 m for Y axis.

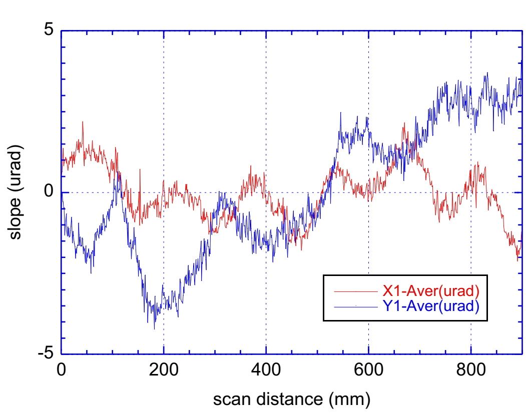

Fig. 3. Pitch (X) and yaw (Y) of Q-Sys air-bearing.

aligned parallel to the air-bearing direction. The temperature should be very stable. We discuss and compare the stability, and repeatability of the test results.

2. Development of the MHPP-LTP-NOM

The NOM can be considered as one kind of penta-prism long-trace profilers (PPLTPs), like that the LTP is one kind of pencil-beam profiler developed by Von Bieren in 1982 [13]. The critical event for the NOM is to apply a precise commercial autocollimator ELCOMAT 3000 to substitute the PPLTP's optical head. The major difference between the original NOM and the MHPP-LTP-NOM is the MHPP application. Furthermore, we are developing our own precise optical head so that we can increase the test range.

2.1. New Monolithic Hollow Penta-Prism (MHPP)

In both the LTP and NOM, the penta-prism plays a significant role. Besides its indispensable function of eliminating pitch error during the test, its stability and accuracy will greatly assist in meeting the demanded nano-accuracy in measurements. To further enhance our instrument's accuracy and stability, we developed a high precision, compact MHPP.

Monolithic Hollow Penta-Prism (MHPP) specifications (Fig. 4) are as follows.

a) Two high-precision mirrors and one glass penta-prism (GPP) are used to constitute a compact MHPP.
b) Two reflection mirrors are in optical contact on two 45° surfaces of the GPP.
c) Mirror surface's quality: $\lambda/100$ with fluid jet polishing.
d) GPP's size: $20 \times 20 \times 25$ mm^3.
e) Accuracy of all GPP angles better than 10 arc s (reach 1 arc s).
f) Hollow penta-prism (HPP) aperture $20 \times 20 \times 20$ mm^3 .
g) Roughness 3–5 Å rms.
h) Transmitted wave front $\sim\lambda/100$.

This MHPP was made by LightMachinary Inc.

Optical contact bonding is a glueless process whereby two closely conformal surfaces are joined, being held together purely by intermolecular forces, so that the bonding distortion is minimized.

The Monolithic Hollow Penta-Prism (MHPP) block is designed to be fixed on the bottom of glass penta-prism (GPP) with low shrinkage optical glue. It will greatly reduce the fixing force compared with that of mechanical fixing. The operational HPP is on the top of the MHPP, some distance away from the gluing surface, so the distortion of the surfaces is also small. Accordingly, the surface distortion should be smaller than the HPP when using two separate mirrors with a mechanical fixing unit.

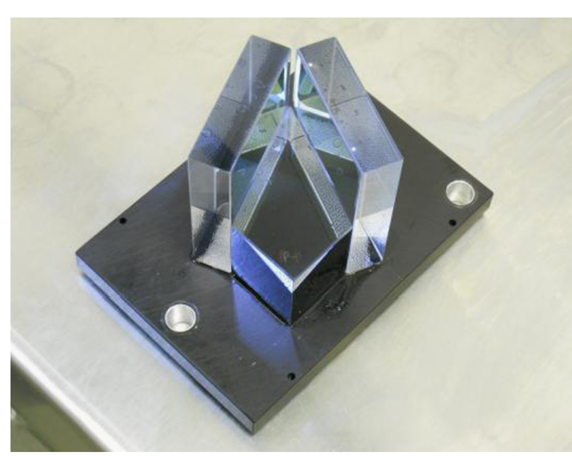

Fig. 4. Optical contact hollow penta-prism.