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Upgrade of long trace profiler for characterization of high-precision X-ray mirrors at SPring-8

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ABSTRACT

The long trace profiler (LTP) at SPring-8 has been upgraded to improve stability and resolution of slope measurement. The performances of the upgraded LTP at SPring-8 are presented by cross-checking measurements on a flat mirror with data obtained using Nanometer Optical Component Measuring Machine (NOM) at the Helmholtz Zentrum Berlin / BESSY-II.

1. Introduction

A long trace profiler (LTP) is used at most of synchrotron radiation facilities for surface slope and shape measurements of X-ray optics. LTP is characterized by a long scan length greater than 1 m, direct non-contact measurement of slope and the unnecessity of reference optic unlike other instruments such as Fizeau or microscopic interferometers. Since the first LTP version with a pencil-beam interferometer [1,2] developed at Brookhaven National Laboratory (BNL) 20 years ago, many variations have been developed worldwide.

The LTP at SPring-8 was based on the standard LTP II with a pentaprism configuration, which was installed in 1999 in collaboration with P. Z. Takacs and Q. Shinan of BNL. From the results of the first round-robin metrology measurements at the APS, ESRF and SPring-8 optical metrology laboratories, it was inferred that the performance of the LTP at SPring-8 was comparable to the performances of the LTPs at the other two facilities [3]. However, it is necessary to upgrade the LTP at SPring-8 because of the aging of various components such as the 1024-pixel double diode array detector and the drive system of an air-bearing slider. The LTP has been completely upgraded in house to achieve high stability and high resolution of slope measurement.

2. Upgrade of LTP

Fig. 1 shows the optical layout and a photograph of the new LTP. Most of the components, such as laser, air-bearing slider, detector, and the optical elements were replaced as shown in Table 1. An intensity-stabilized He–Ne laser, whose output power is 1.5 mW, and a polarization-maintaining fiber are used to shorten stabilization time after change in environments such as temperature. For example, the pointing stability of 0.2 μrad/min requires 15 min after setup, which is 4 times faster than that with previous standard laser. An aperture, whose diameter is 2.2 mm, and neutral density filters allow beam size and intensity adjustments. A polarizing beam splitter divides the beam into two beam: one is incident on the pentaprism mounted on the carriage, and second on a fixed reference mirror. A Fourier transform lens, whose focal length is 1.25 m, focuses the two beams from the surface under test and the reference mirror to a 1.4-megapixel 2D CCD camera. The displacement of the beam reflected by surface under test is proportional to the slope of the surface; on the other hand, the beam reflected by the reference mirror is used to correct the fluctuation of the laser pointing. The single Gaussian beam position on CCD is calculated as a centroid position, which is calculated as a center position of intensity of image by using standard centroid equation:

$$c_x = \sum(P_x I) \Big/ \sum(I), \quad c_y = \sum(P_y I) \Big/ \sum(I)$$

where P represents a pixel's coordinate and I is the intensity of each pixel. Because the calculation speed for centroid position is faster than that of least square curve fitting with second-order polynomial for minimum between double beams, a pencil-beam interferometer [4] is not used for the present setup, which sacrifices spatial resolution.

The height profile is obtained by integrating the slope profile. When the fluctuation in the measured slope profile for a flat mirror is linear, the converted height profile is a quadratic. To achieve a high accuracy measurement result, it is very important to improve stability. Short-term instability is mainly caused by

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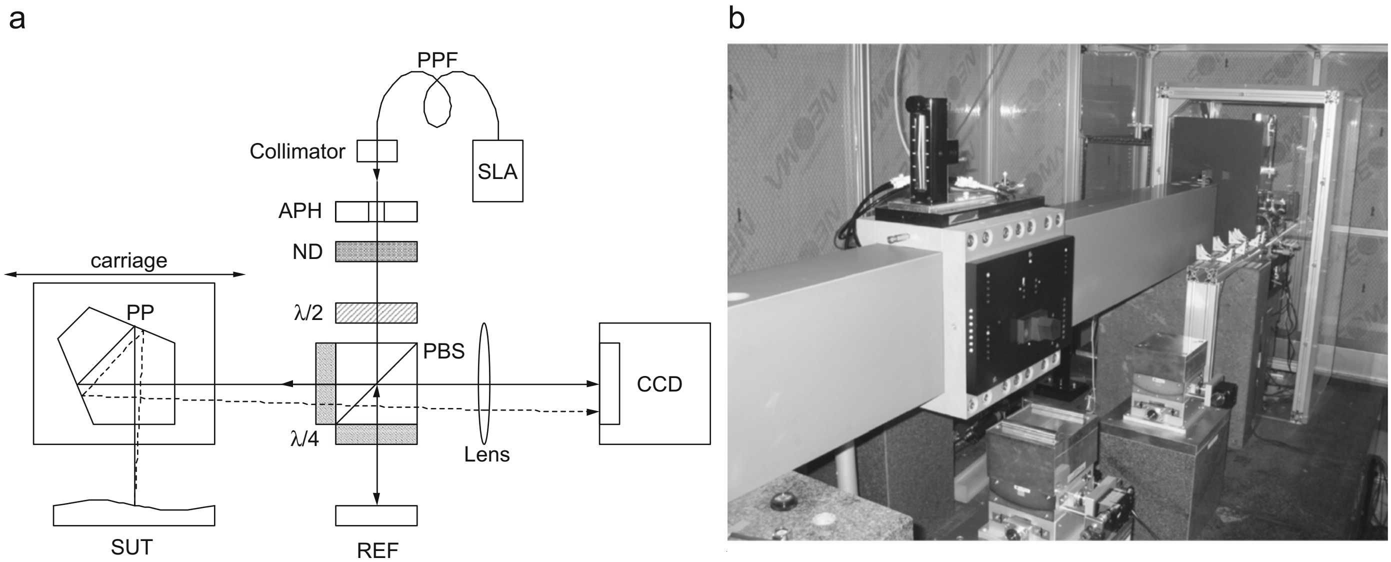

Fig. 1. Schematic of the optical layout and photograph of LTP at SPring-8, where SLA=stabilized He–Ne laser, PPF=polarization-preserving optical fiber, APH=aperture, ND=neutral density filter, $\lambda/2$=half-wave plate, $\lambda/4$=quarter-wave plate, PBS=polarizing beam splitter, PP=pentaprism, SUT=surface under test, and REF=stationary reference mirror.

Table 1
Summary of previous and present LTP's features.

	Previous LTP (1999)	New LTP (2008)
Drive system of air-bearing	Shaft roller with AC servomotor	Traction wire with stepping motor
Scan length	1000 mm	1000 mm
Laser source	He–Ne laser	Stabilized He–Ne laser
Fiber	Single mode fiber	Polarization-maintaining fiber
Connector of fiber	Pigtail	FC/APC
Detector	Dual photodiode array	CCD camera
Pixel size	25 μm × 2500 μm	6.45 μm × 6.45 μm
Number of pixel	1024 × 2	1392 × 1040
Active area	25.6 mm × 5 mm	9 mm × 7 mm
Scan mode	Stepping mode	Flying mode
Scan speed	2 mm/s	10 mm/s
Maximum angular range	± 5 mrad	± 2 mrad

the vibration of the system and air turbulence on the optical path. Long-term instability is caused by thermal fluctuation.

The pentaprism mounted on the air-bearing carriage is the only mobile element. The new ceramic air-bearing system placed on the granite table was fabricated by TOTO Ltd. The working length of the air-bearing system is 1.2 m, the straightness is less than 1 μm/1 m, and the angular motions in pitch and yaw are approximately 5 μrad/1 m. Compressed air is supplied to the air-bearing system via an air receiver with a volume of 2000 l and two high-precision regulators in order to stabilize the air pressure and flow rate. The fluctuations in air pressure are shown in Fig. 2. Compared to previous situation, the fluctuation of air pressure over 1 day is improved by a factor of ten. The air-bearing carriage is smoothly pulled via a piano wire of 0.2 mm diameter using a stepper motor. A linear encoder, whose resolution is 0.1 μm, is mounted on an air-bearing slider.

In order to avoid temporal atmospheric changes, which cause long-term instability, it is essential to use a high-speed measurement system. An image controller and a motion controller are linked to each other for high-speed measurement. A signal from the motion controller, which is generated at each measurement point, is used as a trigger signal for the CCD camera whose frame rate is 10 frame/s. The achieved scan speed of 10 mm/s is 5 times that of the previous scan speed achieved by point-by-point measurement.

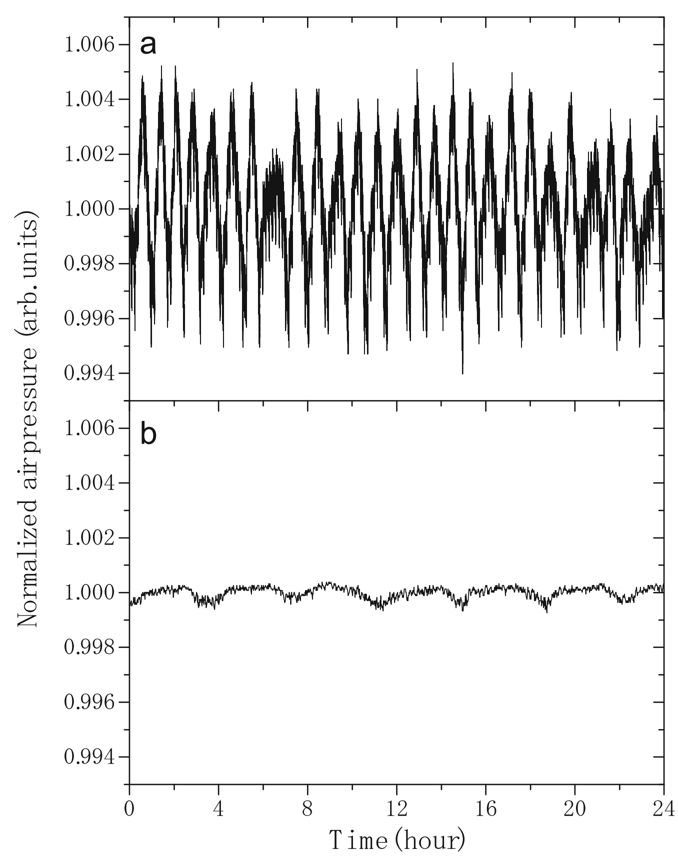

Fig. 2. Fluctuation in air pressure supplied to the air-bearing system measured for previous LTP (a) and present LTP (b).

The granite table is approximately 3 m long, 1.2 m wide, 0.4 m thick and weighs approximately four tons, ensuring higher stability because of its high heat capacity and its low natural vibration frequency. Vibration measurements show that the vibration level is less than half of previous LTP.