Performance of an upgraded long trace profiler at NSRRC

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Abstract. Upgrading the long trace profiler at NSRRC has enabled measurements on mirrors in the beamlines with increased precision. The following working items are included: a 2D CCD detector and its upgraded software, improved straightness of the sliding stage of air bearings, calibration of the system linearity, control of air turbulence in the optical path and some upgraded optics. The factors influencing the stability and accuracy were studied and improved with engineering schemes. Measurements of highly precise flat mirrors and strongly curved mirrors were performed and are discussed.

1. Introduction
A long trace profiler (LTP) is used to measure the surface slope and profile of precision optics in synchrotron facilities [1-2]. Its advantages include a scan length more than 1 m, measurement range of slope up to about 8 mrad and submicro radian precision; it is also a reliable tool to measure strongly curved optics such as a K-B mirror.

LTP II was installed in 1998 in the NSRRC metrology laboratory. A laser and optical head were fixed on the right end of a ceramic beam; a pentaprism was mounted on the air-bearing stage to scan the entire length of a mirror. The temperature of the laboratory environment is controlled within 0.1 °C for 24 h. LTP II was installed on a stable granite to alleviate vibration. In these years, some components such as the driving system of an air-bearing stage, a laser and a CCD were subject to aging and became obsolescent, necessitating an upgrade of the LTP to measure precision optics in the future TPS beamline. In this paper, we present the performance of the upgraded LTP, which includes stability and accuracy issues. We find that the stability is strongly correlated with the air flow; a meter for that air flow and engineering schemes are used to optimize the stability. The calibration of the LTP with a precision autocollimator and a tilting stage is also discussed.

2. Upgrade of LTP
In the old scanning system with an air bearing, a motor and a friction driven-wheel were installed on the stage for the scanning motion, but the flexible cable of the motor added a weight on the stage varying with the position along the ceramic rail, and the rubber wheel deformed after a long operating time. We designed a new air-bearing stage with the motor outside the sliding stage and driven with a traction wire to maintain a smooth movement of the pentaprism, as shown in Figure 1. Figure 2 shows the variation of pitch angle of the old and new air-bearing stages. We found a periodic spike in the old stage during motor scanning, perhaps caused by wear affecting the roundness of the rubber wheel. In the new stage, the spikes disappear and the motion becomes smooth.

The new detector is a 2D CCD camera (Prosilica, 4872 x 3248 pixel, pixel size 7.4 micron). The sensor size is 36.1 mm x 24 mm, equivalent to a maximum angular range about 8 mrad, a little larger...
than for the previous sensor (5 mrad, 25.6 mm x 5 mm). Above the CCD is a read-out with an EPICS-module area detector and a plug-in to analyze the interference pattern; the maximum frame rate is 30 fps. We use Labview for the motor controller of the pentaprism scanning and data acquisition. Data from the area detector and the motor position are input to Labview to calculate the slope and height along the mirror position.

Figure 1. Upgrade of the long trace profiler, including the traction wire of an air-bearing stage, autocollimator calibration and PVC shielding for air turbulence.

Figure 2. Scan stability of old and new stages of the LTP.

3. Improvement of stability
The stability of the LTP is influenced by the thermal conditions, laser propagation and vibration etc. These factors seem not independent -- they sometimes play together. The basic scheme to overcome the vibration of the LTP table is the adoption of a massive granite table. Some optical components are on the incident and reflected beam paths, such as a beam splitter, prism, quarter-wave plate and focusing lens. The individual thermal deformation of each optical component and its holding fixture causes the LTP stability to vary. The enduring stability versus temperature is shown in Figure 3 when we altered the temperature slightly. Such a temperature change evidently has a large influence on the slope reading.

Figure 3. Long-term stability of the LTP with temperature
For the short-term stability, we find that the air turbulence along the laser propagation is important. We use an air-flow meter to monitor the air velocity near the optical path. Adding a PVC shielding box on the granite table and putting a paper pipe along the laser optical path served to decrease the air-flow turbulence. The results are shown in Table 1; the stability improved as the air flow decreased. We found also that the air flow of the air bearing and the vibration of the PVC plate have effects on the stability. Building a stiffer and thermally insulated enclosure and removing the heating power of the CCD, motor, laser in the enclosure would achieve an improvement.

| air velocity/cm s⁻¹ | stability/ micro rad (rms) | remark                  |
|---------------------|---------------------------|-------------------------|
| 12.73               | 2.74                      | without PVC plate shielding |
| 12.73               | 2.17                      | half PVC plate shielding |
| 1.91                | 0.28                      | total PVC plate shielding |
| 1.85                | 0.09                      | total PVC plate and paper pipe shielding |

3. Calibration and linearity error
The linearity error of LTP is crucial in the measurement of the strongly curved K-B mirror; it might be related to the aberration error [3] and the nonlinearity of the CCD [4]. In this work, an autocollimator (Elcomat 3000) was adopted as a reference for the LTP calibration. A flat mirror (1/100 λ) was tilted on a motorized stage to measure the LTP, and another mirror on the same stage for the autocollimator. On initiating the motorized stage, the reading of autocollimator and LTP are simultaneously recorded for about 6 mrad. In this measurement, the tilting stage is placed 30, 50, 70 cm away from the optical head. Figure 4 shows the linearity error of LTP with the mirror at varied distance from the optical head; the horizontal axis is the CCD absolute position, the vertical axis is the difference of the LTP and autocollimator readings. When we measure a curved mirror, the pixel scan range $\theta$ is equal to mirror scan length $S$ divided by mirror radius $R$, $S = R \theta$. For each pixel position one can find a correction value for the measurement condition. We also found that the linearity error altered for the measurement mirror at a varied distance away from the optical head. The reflected beam seemed to strike an imperfect point of the focusing lens and the CCD.

![Figure 4](image-url)  
Figure 4. Linearity error of the LTP with mirror at varied distance from the optical head; one pixel is equivalent to 2.94 micro rad.
To confirm that correction scheme, we measured twice a spherical mirror of radius 9.7 m. The first time it was measured on a stage with pitch angle 0 and at 50 cm from the optical head. The second time the stage was tilted 2 mrad pitch angle. The scan length is from -15 mm to 15 mm on the mirror. In the pitch-zero condition the reflected beam corresponds to the CCD pixels 3520 to 2500; in the 2-mrad condition, it corresponds to pixels 2820 to 1800. Figure 5 shows the scan length on the mirror and its correction value; they are transformed from Figure 4 and the corresponding pixels. In the ideal case, the beam for the LTP measurement would strike the same profile on the mirror; the slope would be the same between the two measurements. In the real condition, the inspection beam struck the same mirror surface but the reflected beam struck the CCD at different points. The slope difference between the first and second measurements is shown in Figure 6. After correction with Figure 5, it was greatly improved. We also found that the slope difference was small near the position 0 mm, which is the same position of our tilting stage in the calibration. The slope difference increased as the measuring position varied away the central point. Detailed calibration at various distances from the optical head might refine the correction.

4. Summary
1. This paper describes the upgrading of the CCD, air bearing and software of the LTP II.
2. The short-term stability of the LTP was studied with an air-flow meter and improved with some engineering schemes.
3. An autocollimator (Elcomat 3000) was adopted as a reference for the LTP calibration. A tilting stage and one curved mirror can serve for self verification of the linearity error of the LTP system. The linearity error depends also on the distance of the measurement mirror from the optical head.

5. References
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