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Abstract

A surface profiler for optical elements used in synchrotron radiation beamlines has been developed. By measuring the precise positions of an incident and reflected laser beam, the surface profile of mirrors and gratings can be obtained. The profile of large mirrors up to 700 mm long and that of any other shape device such as plane and non-spherical mirrors can be also measured. The design concept and preliminary examples of profile measurements are reported.

Keywords: Surface profiler; Optical elements; Synchrotron radiation beamlines

1. Introduction

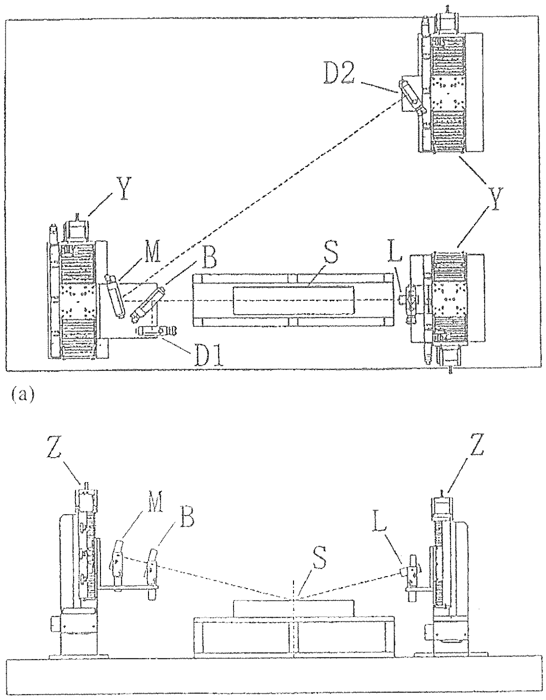
In order to construct a high-performance beamline for synchrotron radiation, characterization of the optical elements is very important. In recent high-performance monochromators operating in the soft X-ray and VUV regions, non-spherical mirrors such as those with ellipsoidal or parabolic figures are not commonly used. However, the use of such mirrors may be advantageous in designing beamlines. For example, the SX-700 monochromator [1] using an ellipsoidal mirror and the monochromator for the ALOISA beamline at ELETTRA [2] using parabolic mirrors show good performance. If the slope error of such mirrors can be reduced, energy resolution and beam size may be improved significantly. For this reason, the development of mirror profilers is important.

Several types of equipment have been developed to measure surface profiles of optical elements, such as interferometers [3] and the Long Trace Profiler (LTP) [4]. A simpler way to measure the profile is to detect the position and direction of a laser beam reflected from the subject surface [5–7]. We are developing a more elegant and precise system based on this principle. The system is also designed so as to be suitable for measuring real SR optical mirrors in terms of size and shape. The principle of measuring profiles is similar to that proposed by Sugawara et al. [7]. In contrast to their design in which the incidence and detection angles to the mirror surface are almost normal, however, we adopted a glancing incidence geometry to facilitate the measurement of plane, spherical and non-spherical mirrors. In addition, we use three stages for the laser and two detectors. Instead of using the position sensitive detector described in Ref. [7], we employ a detector mounted on a linear translation stage (stroke Y; ± 75 mm, Z; ± 75 mm) fitted with an encoder (Heidenhain; LIF101R), to allow detection of the reflected light with a larger solid angle acceptance. This is a big advantage when measuring profiles of spherical mirrors with small radius and a large mirror.

2. Design of the profiler

Fig. 1 shows the top (a) and side (b) schematic views of the profiler. The laser (L) beam (GaAlAs laser, $\lambda = 635$ nm, 5 mW) is directed onto the subject surface (S) at a grazing incidence angle ($\theta \approx 20°$). The beam size at S is about 2 mm diameter. In order to detect the direction of the reflected light, we use two 4-division photodiodes. The two detectors (D1 and D2) and the laser are mounted on the $Y-Z$ linear stages. Each stage is driven by a stepping motor. B is a beam splitter, positioned so that the half of the reflected beam is directed to D1 and the other half to M. M is a plane mirror which reflects the beam to D2. D2 is located on a straight line extended from B–S [1]. The laser beam scans the subject surface by driving the linear stage and D1 and D2 to follow the reflected light via a feedback system. The center of the reflected beam is sought so as to get the same photo-current value at the top (left) and the bottom (right) sections of the 4-division photodiode. The precise positions of L, D1 and D2 can be measured by encoders to an accuracy of 1 μm.

[1] The surface of the 4-division photodiode can also be used as a mirror. Therefore, now we set the D1 on the position M. This reduces the ambiguity coming from the measurement of scale between B and D1 and B and M, etc.



(a)

(b)

Fig. 1. Schematic drawing of the surface profiler. (a) Top view and (b) side view: L: laser diode module; S: subject mirror, B: beam splitter; M: plane mirror; D1 and D2: 4-division photodiodes; Y and Z: translation stages driven by stepping motors.

These values are stored on a computer and the surface profile can be calculated from these. As the arm length from the mirror surface to D1 or D2 is long, accurate measurements of the profile are possible. (D2 is located about 1.6 m from the center of S.). The position errors of the three stages mostly originate from deviation along the X direction perpendicular to the $Y-Z$ plane (less than approximately 10 μm). This value is small compared to the arm length (~ 1 m).

There are two ways to determine the profile of the subject surface by using this system. One uses the two detectors D1 and D2. From the encoder values of the two stages, the straight line M–B–S is calculated. The intersection of this line and the incident laser beam (line L–S) is the mirror surface. In principle, the surface shape can be obtained by scanning the laser beam. However, this method is rather difficult. We have to know the relative coordinates of the components of the system very precisely. In order to know the precise coordinates, the accuracy of the movement of each stage and the relative distance between the devices have been measured by a laser tracker LTD 500 (Leica Inc.) to an accuracy of 0.1 mm. Mirror shape analysis using this method is now in progress.

The other method uses one of the detectors D1 or D2 and is simpler and convenient. It is easy to measure the relative displacement of the detector position from the initial value. The relative displacement of the stage for the laser can also be obtained easily. If we measure the distance between S and D1 or S and D2 and L and S, the change in angle of the surface normal as a function of the laser position can be calculated. The surface profile corresponds to the integral of this change in angle [7]. However, by this method, any deformations parallel to the mirror surface such as uniform contraction of the mirror cannot be detected because in such a case no slope change is apparent.

The present system is very sensitive to mechanical vibration, temperature change and air flow. For this reason, the whole assembly is fixed on an air-suspended vibration-free optical bench (1200 mm × 800 mm size) and covered by a plastic booth.

3. Application to measuring mirror surfaces

The first method described above is rather difficult and the analysis is now underway. Here, we show an example of the application to measuring the slope error of three plane mirrors based on the second method. Fig. 2 shows the surface profiles for three plane mirrors at representative positions. The mirror 0 is a hand mirror used for shaving. The displacement from the perfect flatness is of the order of 10 μm. Mirror 1 is a middle-grade plane mirror used in a monochromator with poor performance. The displacement is about 0.5 μm. Mirror 2 is a high-grade plane mirror used in a grazing incidence monochromator. The displacement is less than 0.1 μm.

In order to characterize the performance of the system, we measure the same mirror surface figure with the interferometer equipment developed at the Photon Factory [3]. The displacement value shown in Fig. 2 is almost identical with that obtained using the interferometer (i.e., of the order of 0.1 μm displacement for mirror 2). We have also succeeded in measuring the radius of a spherical grating using this method.

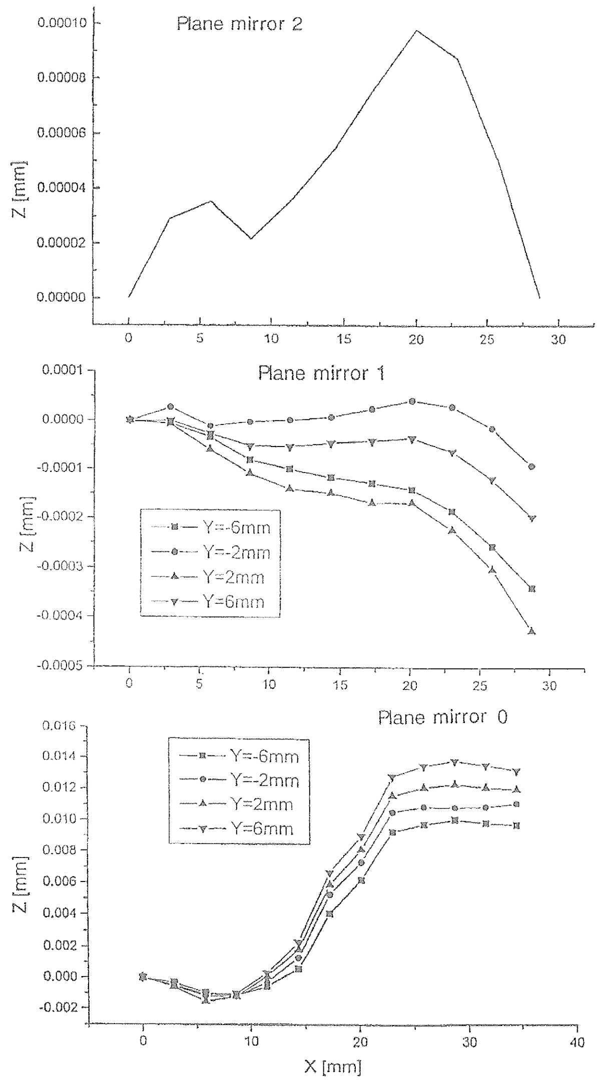


Fig. 2. Surface profiles for three plane mirrors at representative positions.

4. Conclusion

A surface profiler for optical elements used in synchrotron radiation beamlines has been developed. This system has several advantages over previous profilers. Not only spherical and plane mirrors but also non-spherical mirrors such as parabolic, elliptic and ellipsoidal mirrors can be measured. Larger size subjects up to 700 mm can be measured. Although the LTP [4] can also measure the profile for such mirrors, our method may be considered complementary. The radius of spherical mirrors from 1000 mm to ∞ can be measured. Further, the cost of the system is relatively low.

Several improvements of the system are required. Right now, the system does not have sufficient accuracy ($\sim 10\,\mu$rad). In order to measure the slope error within 1 μrad, the beam size should be reduced. The use of a blue laser and/or a collimating system is under consideration. The feedback system is not fast enough. The use of DC servomotors instead of stepping motors may be useful.

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