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A Novel Long-scanning Surface Instrument Design Using a Zeeman 2-frequency Laser

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Abstract

A novel optical profiler design is described in this paper for measuring surface profiles of synchrotron radiation (SR) mirrors. The measurement is based on the combination of an optical heterodyne technique and precise phase measurement without a reference surface. A Zeeman 2-frequency He-Ne laser is employed as the light source. The common-path optical system which uses a birefringent lens as the beam splitter makes it possible to minimize the effects due to air turbulence, sample vibration and temperature fluctuation. The profiler can be used to measure the roughness and curvature of a sample surface based on a special autofocus system. The optical system is mounted on a large linear air-bearing slide, and is capable of scanning over distances covering the spatial measurable period range from several microns to nearly one meter with a very high measuring accuracy.

Key words: Profiler, optical heterodyne technique, synchrotren radiation mirror.

1. Introduction

Many quantitative techniques[1-5] have been developed to measure optical surfaces due to that surface roughness is an important factor in evaluating surface characteristics. Of All the techniques there are two main types: mechanical stylus instruments and optical profilometers. The mechanical stylus instrument is a conventional surface test technique based on a contact method using a sharp stylus. Its measuring accuracy can be several angstroms or less, but the problem caused is that the hard tip and high contact pressure contacting on the surface of a sample easily make some scratches and digs especially on soft material and super-fine surfaces.

Recently noncontact measurement character optical profilometers have been quickly developed. The measuring accuracy is possible near to one angstrom. Up to now the commercial optical profilers only cover the spatial measurable range from two microns to several millimeters. This is not suitable for the measurement of a large or aspheric super-fine optical surface, especially a large cylindrical optical

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surface such as the synchrotron radiation mirror, shown in Fig. 1, which is constructed of silicon carbide with a rhodium coating.

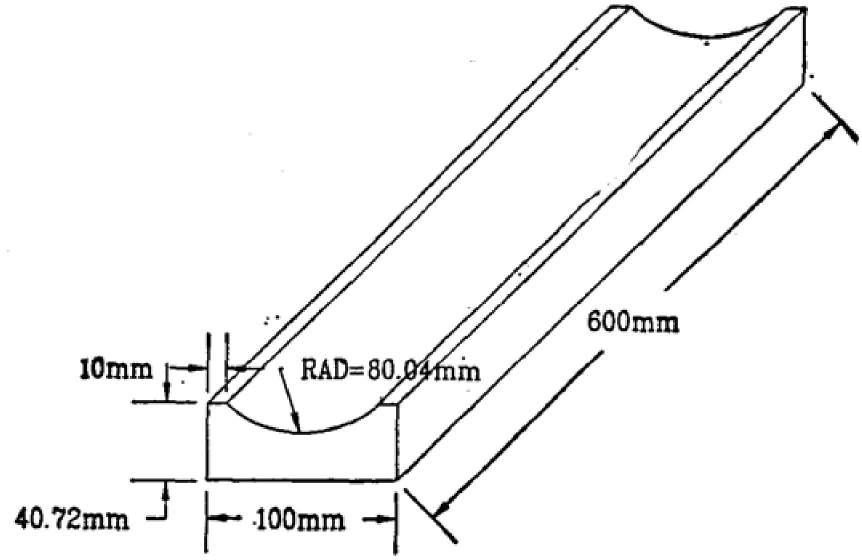


Fig. 1 Diagram of the fused silica cylinder reflect mirror of synchrotron radiation.

To solve the problems mentioned above, Peter Z. Takacs[6~7] has succeeded in the invention of the Long-trace Profiler (LTP) at Brookhaven National Laboratory (BNL), which represents that a new direction in the field of surface testing has been opened. The LTP, based on the pencil-beam interferometer concept, can easily measure large curved optical components in real time with a high accuracy, covering the spatial measurable range from 1 mm to nearly 1 meter.

This paper describes a novel profiler design which can be used as a longscanning surface instrument. The instrument is based on the common-path optical system which employs the common-mode rejection technique without a reference surface. It can cover a spatial measurable range from several microns to nearly one meter. The lowest spatial period can be changed by choosing a different microscope objective.

2. Principle of design

The profiler design is depicted in Fig. 2. A longitudinal Zeeman He-Ne laser, used as the light source, produces a common-path beam which includes two beams with equal intensity and a stabilized frequency difference of 250 kHz. One beam is left circularly polarized; and the other is right circularly polarized. Both beams are expanded through a collimating lens, and the collimated beams are partially reflected and partially transmitted from a beam splitter. The transmitted beams are interfered through a polarizer (P1), received by a photoelectric receiver (R1), where a beat-frequency signal is produced serving as a reference signal which contains the information about the initial phase difference between the both polarized beams. The

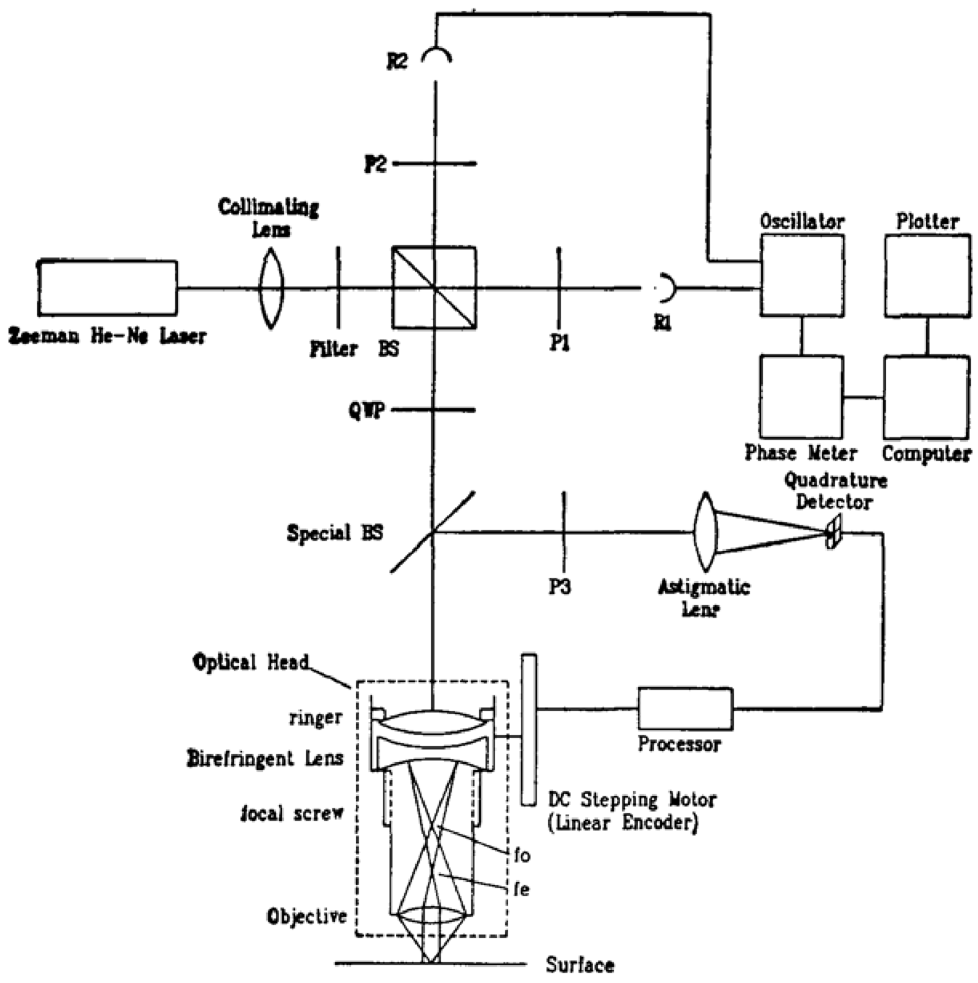


Fig. 2 Schematic diagram of the designed optical heterodyne instrument. The optical head is designed by employing a birefringent lens as the special beam splitter and is controlled by the astigmatic autofocus system

filter is used to enhance the sensitivity of R1 by controlling the beam intensities. The signal-after amplification-is displayed on an oscilloscope and input to a digital phase meter.

The reflected beams from the beam splitter are transmitted through a quarter wave plate (QWP) where they become two coaxis orthogonal linearly polarized beams. The QWP is orientated with its axes at 45 degrees to the crystal optical axis of the birefringent lens. This causes either direction of the two linearly polarized beams orientation is parallel to the crystal optical axis of the birefringent lens. The two beams are then passed through the optical head, which consists of a birefringent lens and a microscope objective. One beam, working as an ordinary ray in the birefringent lens, becomes a focused beam; the other beam, working as an extraordinary ray, becomes a parallel beam. The measured surface is located in the ordinary-ray focal plane of the optical head. The focused beam is reflected from its small focus, and the parallel beam is reflected from a large spot. The area of the large spot overlapping on and is much bigger than the small focus.

Both reflected beams are recombined and collimated through after the optical head. A small part of the collimated beam, which includes the two orthogonal linearly polarized beams with a phase difference information produced by surface roughness, is reflected by a special beam splitter to the autofocus system which can adjust the focus of the optical head on the sample surface. The two transmitted beams is passed through the QWP to be retrieved into orthogonal circularly polarized. They are then interfered through the BS and a polarizer (P2), received by a photoelectric receiver (R2) where a beat-frequency signal is produced serving as a measuring signal which contains the information of surface roughness. The digital phase meter compares the phase angles between the both incoming signals from R1 and R2, respectively, with a very high resolution, up to 0.001 degree. This allows that the quantitative measurement of the optical path difference can be got with a very high accuracy between the average surface levels of the focused beam and parallel beam spots. The surface profile is then provided by a scanning trace.

3. Optical head design

The optical common-mode rejection technique employed in this profiler and the novel optical head design are significant advantages in achieving the high measuring accuracy. The birefringent lens used as a special beam splitter to make its two split beams concentric to each other, and is made of calcite crystal with the optical axis at 90 degrees to the incident beam. Both linearly polarized beams from the QWP are brought to the ordinary and extraordinary focal points, fo and fe, respectively. As the back focal point of the microscope objective is located at the same position as fe, the polarized beam working as extraordinary ray becomes a parallel beam passing through the objective, and the other beam is focused on the sample surface. The area of the large parallel beam spot (~143 microns diameter) is 1250 times greater than that of the small focused beam spot (~4 microns diameter) when using a 40× microscope objective. When the two reflected beams are recombined

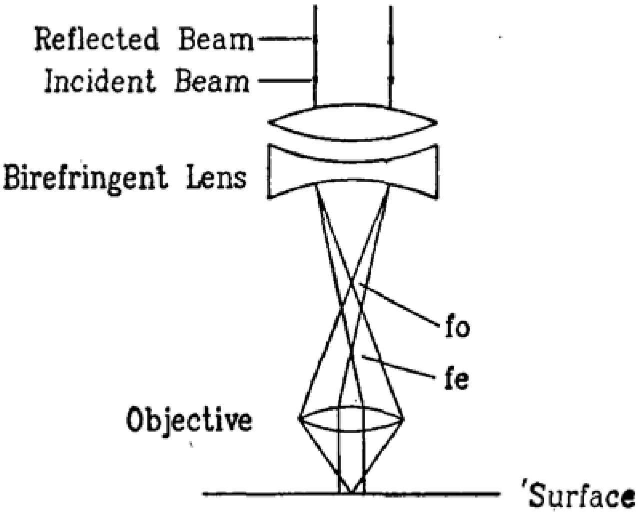
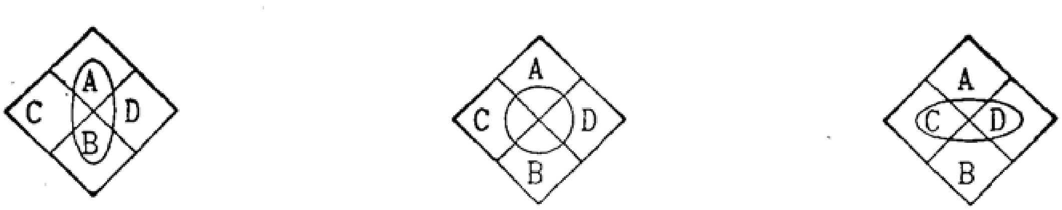


Fig. 3 Optical head configuration. The back focal point of the microscope objective is located at the same position as that of the extraordinary ray of the birefringent lens. The both reflected beams from the surface being tested are recombined and collimated through the optical head

through the optical head, the phase, Φ, of the beam reflected from the small spot is determined by the surface level, H, and the phase, Φ_0, of the other performs an average level integrated over the large parallel beam spot which can be seen as a reference level, H_0. When the beams scan on the surface, the level of their phase difference follows the surface irregularity. As the both beams are always concentric to each other, the sample vibration, air turbulence and temperature fluctuation cause the same optical phase changes to each beam. The common-mode rejection minimizes these perturbations in the optical heterodyne phase measurement. Meanwhile, the measurement of surface roughness, described by $\Phi-\Phi_0$ due to that there is a relationship between $(H-H_0)$ and $(\Phi-\Phi_0)$ which is $(\Phi-\Phi_0)=4\pi(H-H_0)/\lambda$ (λ is laser wave-length.), is not sensitive to the beam intensity varration. Hence, the designed profiler can work with a very high degree of measuring accuracy in the ordinary experimental condition.

4. Autofocus system

An astigmatic autofocus system is utilized to keep the optical head at the position where the ordinary ray is focused by the birefringent lens on the surface being measured. The astigmatic lens is combined with a group of cylindrical lenses. A four quadrat detector is located at the position between the two foci of the astigmatic lens, so that a circular beam spot pattern is on its surface when a collimated beam is incident on the lens, shown in Fig. 4(b). The sign and amplitude of the focus-position error signal produced by the detector system is determined by the difference between the signal sums from quad cells A and B and quad cells C and D. A linear-encoded stepping motor is employed to transfer the optical head up and down according to the focus-position error signal.



(a) (b) (c)

Fig. 4 Optical spot pattern on the quadrature detector when the sample surface position is (a) too far; (b) in focus; (c) too close

When a small part of both reflected beams is input to the autofocus system, a polarizer (P3), whose polarization direction is oriented at 90 degrees to the polarization of the reflected beam from the large spot, will only let the reflected beam from the small focused beam spot pass through the astigmatic lens to the quadrature detector. When the sample surface is located in the focal plane of the ordinary ray of the optical head, the resulting pattern on the detector is a circle and the focus-position error signal is zero. When the surface is out of focus, too far or too close, the reflected beam from the small spot will be convergent or divergent. The resulting pattern on the detector surface will be an ellipse, with a larger vertical than horizonal axis or reverse, respectively. Hence, the focus-position error signal will be positiveor negative, and the linear-encoded stepping motor will move the optical head up or down, respectively. As the translating distance of the motor is 25 mm with a resolution of 0.1 micron, the instrument is capable of realizing the measurement of an optical curved surface easily.

The total optical system is mounted on a large linear air-bearing slide which is nearly one meter long with excellent stability and has an expected angular repeatability. The tilt angle error of the dynamical optical head caused by its own weight and other factors when moving can be measured in real time by a sensitive electronic autocollimator, then corrected. The spatial period range of this instrument is, therefore, from 4 microns to nearly one meter when a 40 × microscope objective is chosen.

5. Present status

As the writing of this paper, a large Dover Model 850 linear air-bearing slide long with the work distance of 965 mm and a long granite optical table has been already utilized in our laboratory. The astigmatic auto focus system is being produced. Some optical elements are being delivered. The experimental results and analyses will be reported in near future.

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用塞曼双频激光器作光源的一种新颖长扫描表面的仪器设计

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提 要

本文报道一套光学结构用于同步辐射反射镜表面轮廓高精度大面积的测量。采用了光学外差测量与接收技术，以伺服聚焦双折射透镜组分离“o”光与“e”光的聚焦区域，并再共轴组合比较其相位差，从而获得表面起伏的误差值。线性运动的测量工作台使镜面可测量范围从数微米到一米，而最小起伏量及曲率可达很高的测量精度。

关键词： 轮廓仪，光外差技术，同步辐射反射镜。