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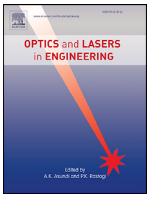

Wavelength-dispersed optical-line scanning super-resolution interferometry for fast measurement of precision surface

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ABSTRACT

A new precision surface measurement technology which is based on wavelength-dispersed optical-line scanning interferometry and is endowed with both vertical super-resolution and lateral super-resolution is proposed. The light from a broadband light source is dispersed by a blazed grating to be an optical line scanning the surface to realize fast three dimensional (3D) surface measurement. Vertical super-resolution of less than 1 nm is obtained by the means of optical interferometry. By employing an optical amplitude pupil filter, the lateral resolution in one direction is achieved to be less than 0.5 μm. And by expanding the interferometric beam before being detected by a linear array CCD, the lateral resolution in the other direction can be less than 0.8 μm. The wavelength of the light reflected from each measured point on the surface is unvariable and the measurement results can be wavelength-traceable exactly.

1. Introduction

Optical interferometry has been widely used for the measurement of precision and ultraprecision surfaces [1–9] because of its prominent advantages such as non-contact, high measurement resolution, high measurement precision, etc. Different optical interferometric surface measurement systems have been developed. X Liu [1] and L Chen [2] reported lateral shearing interferometers for precision surface measurement which is insensitive to external vibration and environmental disturbances. Ya Huang [3] used conjugate differential method to realize absolute measurement of optical flat surface shape and the deviation of RMS value of the measurement results was less than 0.3 nm. H Broistedt [4] developed a random-phase-shift Fizeau interferometer of which the RMS of ten repeated measurement results is about 0.004 wavelength. References [5–9] researched on low coherence interferometry for surface measurement which can measure surfaces with different characteristics. Almost all of the available surface interferometric measurement technologies are point-scanning measurement mode. As the results of three dimensional (3D) surface measurement can depict the characteristic of the surface precisely, almost all of the precision and ultraprecision surfaces are required to be 3D measured. In order to release 3D surface measurement, it is needed for measurement technologies of point-scanning mode to scan in two lateral directions, which results in complicated configuration and low measurement speed. The other drawback of the available optical surface interferometric measurement technologies is that the lateral resolution limited by the effect of optical diffraction. And thus the lateral resolution is determined by the size of airy disk of the focused beam, the diameter of which is about several micrometers and can not satisfy the requirement of lateral super-resolution measurement for ultraprecision surfaces.

In this paper, we propose a new precision surface measurement technology with optical-line scanning measurement mode and is endowed with both vertical super-resolution and lateral super-resolution. 3D surface measurement can be realized for the system just scanning the surface in one direction, which increases the measurement speed and simplifies the configuration of the system simultaneously. By the means of optical interferometry, the vertical resolution is achieved to be less than 1 nm. By using an amplitude pupil filter and expanding the optical beam in one direction, the lateral resolution in two directions can be less than 0.5 μm and 0.8 μm, respectively. The light of the wavelength reflected from each measured point on the surface is unvariable, not being influenced by the drifting of the spectrum of the light source, and therefore the measurement results can be wavelength-traceable exactly.

2. The principle of the measurement system

2.1. The process of the measurement

The schematic diagram of the measurement system is shown in Fig. 1. A super luminescent diode (SLD) connected with an optical fiber pigtail emits light with center wavelength 850 nm and bandwidth 45 nm into the system. The light is collimated with a Grin lens and is projected onto a blazed grating (G) with incident angle 30.4° The parameter of the

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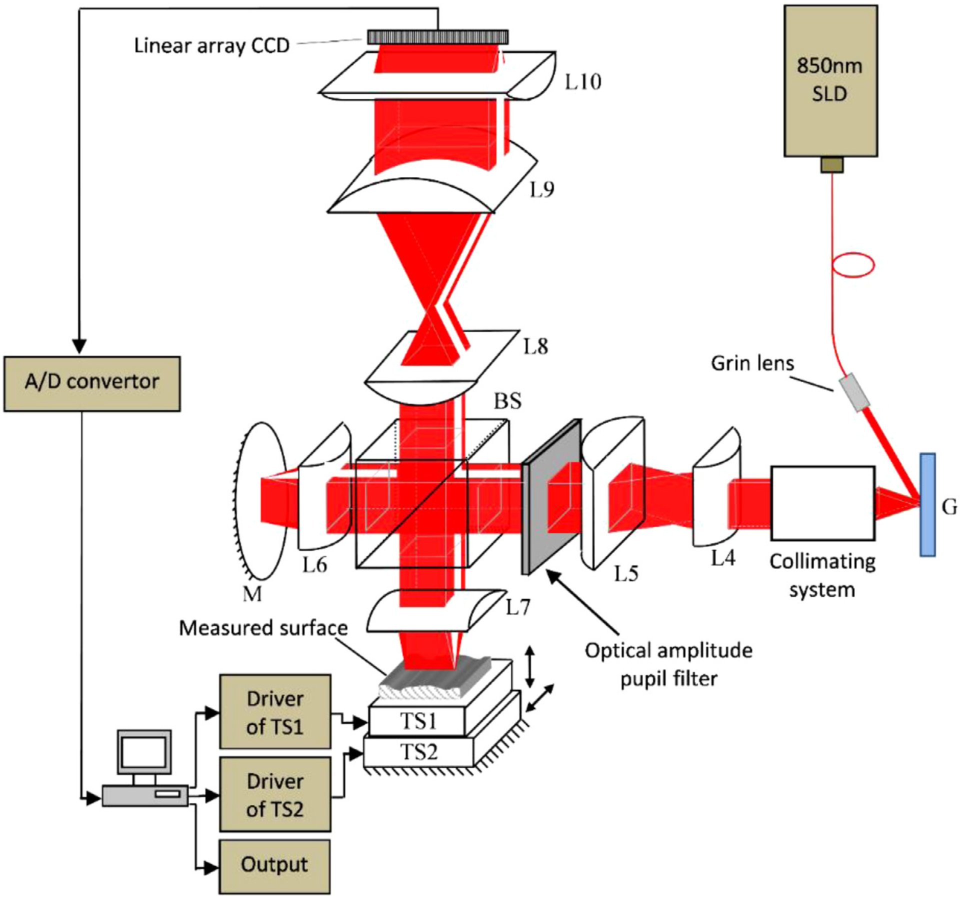

Fig. 1. The schematic diagram of the measurement system.

blazed grating is 600 lines per mm. The collimated beam is dispersed to be a fan-shaped plate which is symmetric about the perpendicular line of the surface of the blazed grating. The fan-shaped plate is shaped to be a parallel plate with different wavelengths distributing continuously in the transverse direction. The parallel plate is expanded to be a parallel beam using flat convex cylindrical lenses L4 and L5. The parallel beam transmits through an optical amplitude pupil filter and the beam is shaped to be a parallel beam with hollow band in the optical axis area, as shown in Fig. 1. The parallel beam with hollow band is split into two beams by a beam splitter (BS). One beam is focused onto the reference mirror (M) by a flat convex cylindrical lens (L6) and the light is reflected back to BS again by M. The other beam is focused onto the measured surface by another flat convex cylindrical lens (L7) and the light is reflected back to BS again by the measured surface. Different wavelength in the light beam is focused onto different measured point on the surface. The reflected light from a measured point is endowed with the height information of the measured point. The two reflected beams are combined at BS and interfere each other. The interferometric beam is expanded in one direction by two flat convex cylindrical lenses (L8 and L9) and is focused by a flat convex cylindrical lens (L10) onto a linear array CCD. The interferometric signal with different wavelength is detected by different pixel of the CCD, which can be expressed as Eq. (1).

$$I_i = I_{i0}\left[1 + V_i \cos\left(\frac{2\pi\Delta_i}{\lambda_i}\right)\right] \tag{1}$$

Where I_i is the interferometric signal detected by the ith pixel of CCD, I_{i0} is associated with light power, V_i is the visibility of the interferometric signal, λ_i is the wavelength of the interferometric signal, Δ_i is the optical path difference.

During the measurement, a vertical translation stage (TS1) is driven to scan the optical path linearly and CCD detects the interferometric signal simultaneously. The interferometric signal will has the form as Eq. (2).

$$I_i = I_{i0}\left[1 + V_i \cos\left(2\pi\frac{\Delta_i - 2vt}{\lambda_i}\right)\right] \tag{2}$$

Where v is the scanning speed of TS1, t is the scanning time, and the other characters have the same meaning as they have in Eq. (1).

Each of the detected interferometric signals is converted to be digital signal by an A/D converter and is processed by a software program. The phase difference between two interferometric signals from adjacent pixels of the CCD that are corresponding to adjacent measured points on the surface can be obtained. The height difference between adjacent measured points can be measured by Eq. (3).

$$\Delta h_i = \frac{\Delta\varphi_i}{4\pi}\lambda_i \tag{3}$$

Where Δh_i is the height difference between adjacent measured points on the surface, $\Delta\varphi_i$ is the phase difference between two interferometric signals, λ_i is the wavelength of the interferometric signal detected by ith pixel of CCD. The height difference between every two adjacent measured points can be measured using Eq. (3) and 2D surface measurement can be realized without scanning action, which improves the measurement speed greatly. 3D surface measurement can be realized by the optical line scanning the measured surface.

2.2. The configuration and the function of the collimating system

In the experiments, the diameter of parallel beam from the Grin lens is about 0.58 mm and the incident angle of it to the blazed grating is