Invited Paper

Beam scanning laser interferometer with high spatial resolution over a large field of view

Osami Sasaki, Tsuyoshi Saito, Samuel Choi, and Takamasa Suzuki

Faculty of Engineering, Niigata University, 8050 Ikarashi 2, Niigata-shi 950-2181, Japan
Fax 81-25-262-6747   E-mail: osami@eng.niigata-u.ac.jp

ABSTRACT

It is difficult in interferometric metrology to maintain high spatial resolution over a large field of view. In this paper this characteristic is achieved by scanning two focused laser beams over an object surface and a reference mirror surface, respectively, with a rotating mirror, a lens, and a polarization beam splitter. An electric-optic phase modulator generates the phase difference of a sinusoidal waveform of 10 MHz between the two focused beams. Sinusoidal phase-modulating interferometry is used to calculate the phase of the interference signal caused by the two focused beams. The scanning speed of the beams is 20 m/s, and the sampling interval of the interference signal is 1/80 microseconds. The spatial resolution is 2.0 microns over the measurement region of 18.8mm. The measurement results show that the measurement error is less than 5nm.

Keywords: beam scanning, interferometer, sinusoidal phase-modulation, polarization interferometry, surface profile measurement

1. INTRODUCTION

Maintaining high spatial resolution over a large field of view is difficult in general interferometers using a CCD image sensor to detect the interference signal. Interferometric microscope measurements yield high resolution, but only over a small area. Other general interferometers can measure large areas, but they fail to provide the necessary spatial resolution. High spatial resolution over a large field of view is a very important characteristic for large size objects. This characteristic will be achieved by scanning a laser beam over an object surface and a reference mirror surface in an interferometer. The laser beam scanning has been used to get a high-accuracy measurement insensitive to mechanical vibrations with differential heterodyne interferometry [1, 2]. In this paper the laser beam scanning is utilized for achieving a high spatial resolution over a wide measurement region in an interferometer constructed as described below. A collimated laser beam from a laser diode is incident into an electric-optic phase modulator (EOM) to generate sinusoidal phase-modulation between the two orthogonal polarization components. The beam passing through the EOM is reflected by a rotating mirror and moves over a surface of a polarization beam splitter with the help of a lens to produce a focused beam scanning over an object surface and a reference mirror surface. The two focused beams are reflected by the surfaces and travel back along the same path as the original beam, and a sinusoidally phase-modulated interference signal is detected with a photo-multiplier detector. In the inteferrometer, the scanning speed of the focused beam is 20 m/s, and the frequency of the sinusoidal phase-modulation is 10 MHz. The sampling interval of the interference signal is one-eighth of one period of the sinusoidal phase-modulation, and this sampling interval is 0.25 microns in the scanning position on the object

2011 International Conference on Optical Instruments and Technology: Optoelectronic Measurement Technology and Systems, edited by Xinyong Dong, Xiaoyi Bao, Perry Ping Shum, Tiegen Liu, Proc. of SPIE Vol. 8201, 82010J
 · doi: 10.1117/12.910102

surface. The spatial resolution of the surface profile measurement is 2.0 microns because the 8 sampled values of the interference signal provide one measured value of the surface profile. The number of the sampling points is 75200 and the measurement area is 18.8mm. The measurement results show that the measurement error is less than 5nm with a high spatial resolution over the wide measurement region.

2. PRINCIPLE

A configuration of the beam scanning interferometer is shown in Fig.1. A collimated beam of a liner polarization from a laser diode (LD) is incident into an electro-optic modulator (EOM) to generate sinusoidal phase-modulation between the two orthogonal polarization components of the incident beam. The voltage applied to the EOM is $V_0\cos\omega_c t$, and the phase difference between the two orthogonal polarization components of the beam going out from the EOM is expressed by $Z\cos(\omega_c t+\theta)$. The two components are denoted by U_x and U_y, respectively. The modulation amplitude Z is proportional to the amplitude of the applied voltage V_0. The beam diameter is enlarged to the size of a with lenses L1 and L2. The beam passing through a beam splitter (BS) is reflected by a rotating mirror (RM) and reaches to a polarization beam splitter (PBS) being converted to a converging beam with a lens L3. The beam of the component U_x passes through the PBS and its focused beam is incident onto a surface of an object (OB). The beam of the component U_y is reflected by the PBS and its focused beam is incident onto a plane of a reference mirror (MR). The distance between the beam position on the RM and the lens L3 is the focal length f of the lens L3. The distance between the lens L3 and the focusing position of the two beams is also the focal length f. The diameter of the beams focused by the L3 is $\phi_f=1.22(\lambda f/a)$. In this configuration the two focused beams are scanned on the surfaces of OB and MR, respectively, by rotating the RM with the rotational velocity R_v. The scanning position of the focused beam on OB is given by

$$x=f[\tan\gamma(2\pi R_v t)]\,, \qquad (1)$$

If $\cos^2\gamma \cong 1$, the scanning velocity is given by

$$V_s=dx/dt=2\pi f R_v\,. \qquad (2)$$

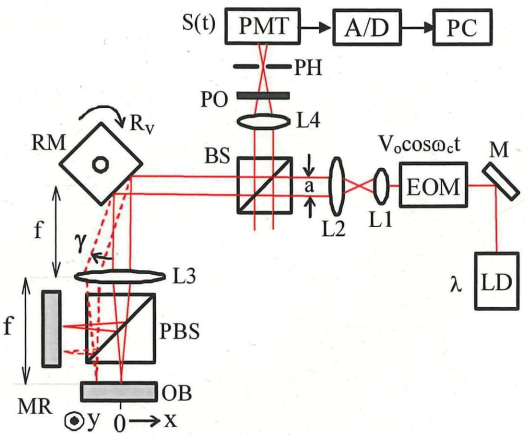

Fig.1 Configuration of the beam scanning

The beams reflected by the surfaces of OB and MR, respectively, go back along the same path as the original beam and are converted to the collimated beams. The two collimated beams are reflected by the BS to pass through the lens L4 of a focal length f_4 which makes the focused beams on the pinhole (PH) with a diameter ϕ_p. The L4 and the L3 consist of a conjugate focusing configuration. The polarization PO produces the interference between the two components of U_x and U_y and the interference signal to be detected with the photo multiplier is expressed by

$$S(t)=\cos\{(z\cos\omega_c t+\theta)+\alpha_0+\alpha(t)\} . \qquad (3)$$

The phase $\alpha(t)$ is proportional to the optical path difference between U_x and U_y with a constant value of α_0 and, it is expressed by

$$\alpha(t)=(4\pi/\lambda)r(t) , \qquad (4)$$

where r(x) is a surface profile of the object. The signal S(t) is sampled at intervals of $T_c/8$ with the A/D converter AD, where $T_c=1/f_c=2\pi/\omega_c$. The sampling interval of the signal S(t) in the scanning position is $\Delta d=V_s(1/f_s)$, where the sampling frequency of the AD is $f_s=8f_c$.

3. CHARACTERRISTICS OF THE INTERFEROMTER

The following values were used: λ=658 nm, f_c=10 MHz, a=10 mm, f=70 mm, ϕ_f=5.6 μm, R_v=23 rps, V_s=20.2 m/s, Δd=0.25 μm, f_4=50 mm, and ϕ_p=100 μm. Figure 2 shows the interference signal S(t) detected when the OB was an optical mirror with a quarter wave flatness. The horizontal axis shows the sampling number I_s of the signal. The total number of the sampling points was N_s=75200, and the scanning width or the measurement region was d= $N_s\Delta d$=18.8 mm. The scanning time was $T_s=N_s/f_s$=0.94 mm. The amplitude of the interference signal was small on the both sides of the measurement region. Portions of the interference signal from I_s=15000 and I_s=54000 are shown in Figs.3(a) and (b), respectively. It is seen that the waveforms of the interference signals shown in Fig.3 are identical to the theoretical waveforms of the sinusoidally phase-modulated signal. One value of the phase α was calculated from the Fourier transform of 8 sampled values within one period T_c with sinusoidal-phase modulating interferometry [3]. This computation was repeated every 8 sampled values sequentially for all of the sampling points of N_s. Therefore the measurement interval or the spatial resolution was $\Delta x=8\Delta d$=2.02 μm. The phase distribution calculated from the interference signal of Fig.2 is shown in Fig.4, where the horizontal axis is the measurement point number I_m, and the total number of the measurement points was $N_m=N_s/8$=9400. The modulation amplitude and initial phase were z=2.0 rad and θ=0 rad, respectively. It is expected that the measured phase distribution is nearly a linear line because the object was the optical mirror, but the measurement result shown in Fig.4 is different from a linear line. The variation range of the phase distribution was about 2 rad. The other position on the surface of the optical mirror was measured by displacing the optical mirror along the y-axis. The measure result is shown in the lower part of Fig.5, where a tilted component was subtracted from the raw phase distribution. In the upper part the measurement result of Fig.4 without a tilted component is shown together to compare these two results. Since these two distributions are almost the same, the phase distributions shown in Fig.5 are regarded as an aberration of the interferometer itself which is caused by a position error of the rotating mirror RM, an aberration of the lens L3, and so on. Considering the time-variation of the phase distribution and the aberration of the interference, the measurement error in the phase distribution is 0.1 rad which corresponds to 5 nm in the surface profile.

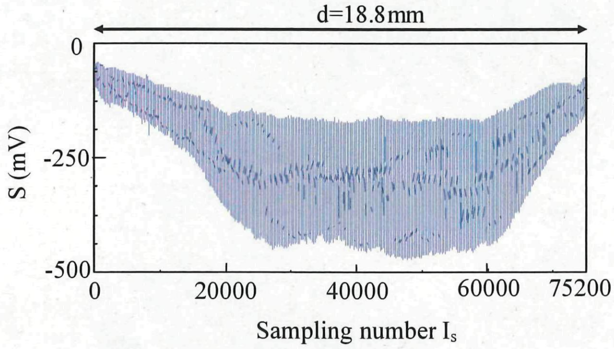

Fig.2 Interference signal detected when the object was an optical mirror.

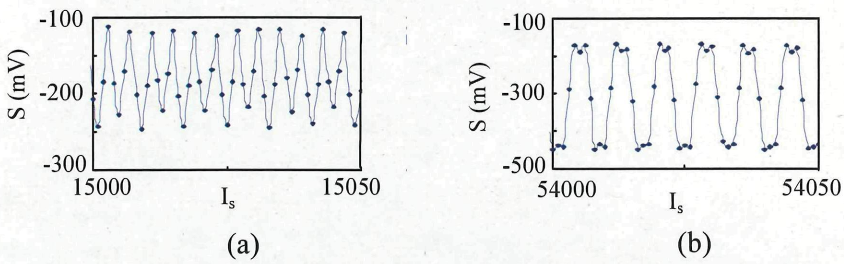

Fig.3 Portions of the interference signal shown in Fig.2.

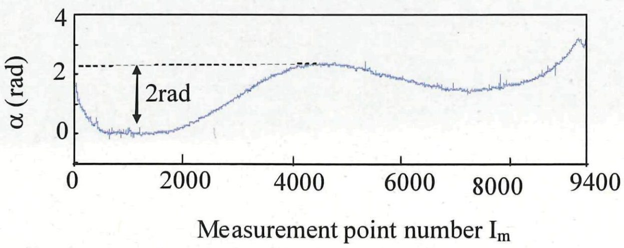

Fig.4 Phase distribution calculated from the interference signal of Fig.2.

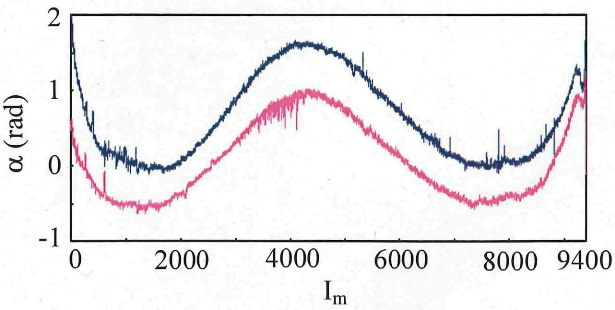

Fig.5 Phase distributions measured for different lines on the optical mirror surface.

4. MEASUREMENT OF A SURFACE OF A TRANSPAREN PLATE

The object was an acrylic plate with 1mm thickness. A profile of the front surface of the transparent plate could be measured with this interferometer because the light reflected from the focused point of the beam was selectively detected through the pinhole PH as shown in Fig.1. The light reflected by the rear surface of the transparent plate did not produce an interference signal with the reference beam. Figure 6 shows the detected interference signal. In this case the total number of the sampling points was reduced to N_s=74800, and the measurement region was d=18.7 mm. The aberration of the interferometer shown in Fig.5 was abstracted from the phase distribution calculated from the interference signal of Fig.6. The resulting phase distribution is shown in Fig.7, where the total number of the measurement points was $N_m=N_s/8=9350$. The variation range in the phase distribution was 29 rad which corresponds to 1.52 μm variation range in the surface profile. The phase distribution between I_m=4500 and I_m=5500 was magnified to obtain the distribution shown in the upper part of Fig.8. The same measurement was repeated and obtained the distribution shown in the lower part of Fig.8. The two distributions shown in Fig.8 are almost the same except small variations less than about 5 nm. For an example, a fine structure of the surface profile with 20 μm width and 16 nm depth can be observed as indicated in Fig.8.

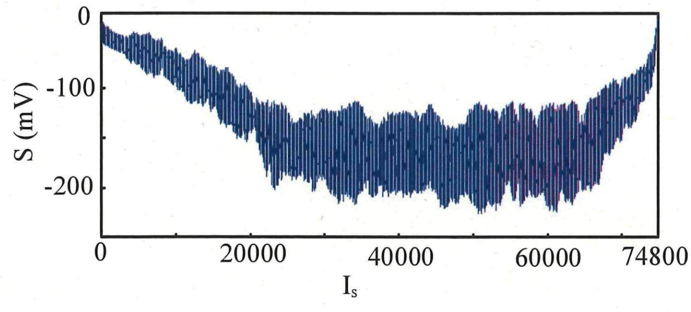

Fig.6 Interference signal detected when the object was an acrylic plate.

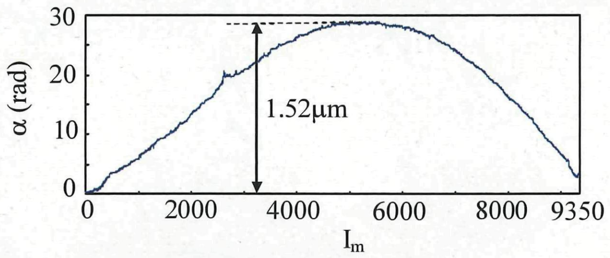

Fig.7 Phase distribution calculated from the interference signal of Fig.6.

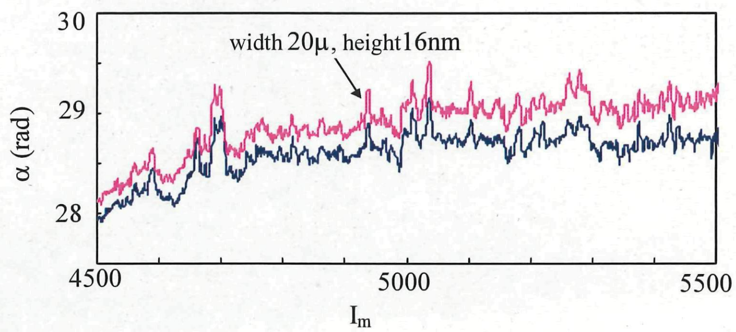

Fig.8 Phase distributions measured at different times for a portion of Fig.7.

5. CONCLUSIONS

Since the laser beam was scanned with the high scanning speed of 20 m/s, the high sinusoidal phase-modulation of 10 MHz was generated with the electric-optic phase modulator between the two orthogonal polarization components of the beam from the laser diode. These two polarization components were used as the object wave and the reference wave, respectively, to employ the polarization interferometry. A high spatial resolution of 2.0 microns over a large measurement region of 18.8mm was achieved by scanning the two focused laser beams over an object surface and the reference mirror surface, respectively, with the rotating mirror and the lens. The measurement results showed that this beam scanning interferometer could detect fine structures of 20 μm width and15 nm depth existing in the surface profile with the measurement error less than 5nm. Since the interference signal was detected with a confocal configuration, it was possible to measure selectively the profile of the front surface of the acrylic plate with 1mm thickness.

REFERENCES

1. H. Martin, K. Wang, and X. Jiang, "Vibration compensating beam scanning interferometer for surface measurement," Appl. Opt. **47**, 888-893 (2008).
2. C. Song, T. J. Kim and D. Gweon, “Beam scanning confocal differential heterodyne interferometry ,” Int. J. of Optomechatronics 1, 27-45 (2007).
3. O. Sasaki and H. Okazaki, "Sinusoidal phase modulating interferometry for surface profile measurement," Appl. Opt. **25**, 3137-3140 (1986).