Micro-nano Position Control System Using Interferometric Phenomena

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Abstract

We proposed a non-contact micro-nano biaxial position sensor based on moiré interference phenomena. The position control is done to an arbitrary position by PI control, and the positioning accuracy at the positioning point is evaluated. In the case of 10 μm grating pitch, standard deviations 0.07nm (X-axis) and 0.23nm (Y-axis) are estimated under proper conditions.

1 Introduction

For micro-nano processing, DNA and cell observations, optical device alignment system for next-generation optical communication and semiconductor production equipment, a high resolution position sensor is needed for the development of nanotechnology. Several displacement measurement methods and alignment methods have been proposed by many researchers[1-4]. Some of the studies have been achieved accuracy with the order of sub-nanometers. However, a lot of studies have not been satisfactory about repeatability.

We had proposed a non-contact micro-nano uniaxial displacement sensor based on moiré interference phenomena[5]. This method can detect a relative displacement between a measurement object and a working reference plane using diffraction gratings. Even if you repeatedly attached and removed the measurement object on the stage, the displacement measurement can be done in high accuracy. And it is not influenced from the fixing accuracy of attachment, because of a direct measurement from the gratings on measurement object and reference plane.

In this paper, we proposed a non-contact micro-nano biaxial position sensor based on moiré interference phenomena. The moiré signal which passes through two gratings is expressed for a function of displacement between gratings. The moiré signal

intensity varies periodically as substantially sinusoidal waveform. Therefore, we use moiré signal for the position sensor. The biaxial position of X and Y directions can be calculated from zero-order diffracted beams detected by photo-detectors.
We also proposed positioning control method for this sensor. The position control is done to an arbitrary position by PI control, and the positioning accuracy at the positioning point is evaluated. To evaluate the characteristics of the sensor, we control the sensor using a circular interpolation positioning at several conditions as an example.

2 Experimental setup

Schematic of the proposed biaxial position sensor is shown in Fig.1. The sensor consists of a light source (wavelength: λ), two pair of gratings (pitch: P) and two photodetectors. The light beams which are equally divided by half mirror are normal incidence to the two pair of gratings. Each of first gratings of grating pairs is fixed on the precision XY motion stage. This stage is movable in perpendicular direction to light axis. In this technique, we measured entire transmitted light intensity. Therefore, it is very simple sensor and do not need an image sensor.

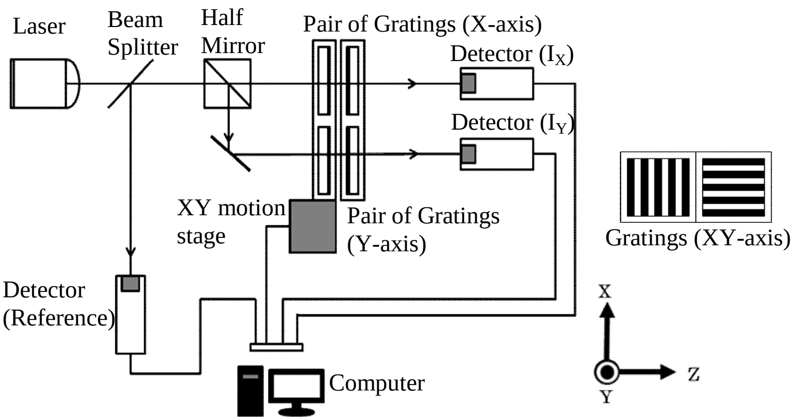


Figure 1: Schematic diagram of the proposed biaxial position sensor

Detected moiré signal intensity is expressed as a function of the wavelength of light from optical source, the gap(G) between two gratings and the grating period, and the measuring range of the moiré signal intensity was limited to the grating period[6]. Therefore, the displacement is calculated by the moiré signal intensity. The experimental conditions are wavelength: λ= 670 nm, pitch: P= 10 μm and gap: G= 490 μm.

The position control is done to an arbitrary position by PI control as following equations.

$$D_x = K_{Px} \times (I_{xg} - I_x) + K_{Ix} \int (I_{xg} - I_x) dt \quad (1)$$

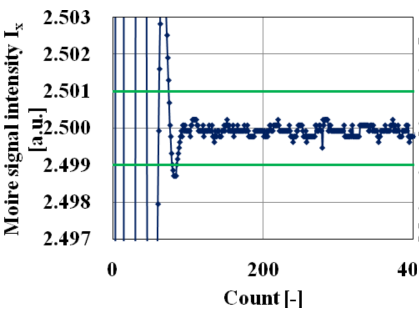
$$D_y = K_{Py} \times (I_{yg} - I_y) + K_{Iy} \int (I_{yg} - I_y) dt \quad (2)$$

Here, Dx and Dy are manipulative variables, Kpx and Kpy are proportionality coefficients, Kix and Kiy are integral coefficients, Ixg and Iyg are target values and Ix and Iy are present values. Sampling frequency is set to 1 Hz.

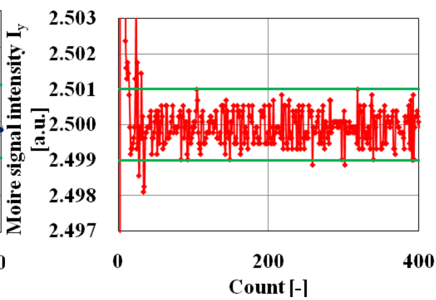
3 Results and Discussion

Figure 2 shows an example of point to point automatic control for X and Y directions. The experimental conditions are Ixg= Iyg= 2.5 a.u., Kpx= 1000, Kix= 300, Kpy= 700, Kiy= 300. In Fig. 2, two straight lines show upper and lower predetermined reference intensities.

The moiré signal intensities for X and Y directions are controlled towards the target value automatically. And even if the sensor gets out of the reference intensities by disturbance and/or vibration, it is again controlled automatically as shown in Fig. 2. The results also indicated that setting time is approximately 87(X-axis) and 16(Y-axis) counts. Using the previously observed characteristic between moiré signal intensity and displacement[6], standard deviations 0.07nm (X-axis) and 0.23nm (Y-axis) are estimated.



(a)X direction



(b) Y direction

Figure 2: Results of point to point automatic control for (a)X and (b)Y directions

Figure 3 shows examples of circular interpolation position automatic control. The experimental conditions are same as Fig.2. The target values Ixg and Iyg are calculated by equations 3 and 4.

$$I_{xg} = R\cos\theta + O_x \quad (3)$$

$$I_{yg} = R\sin\theta + O_y \quad (4)$$

Here, R=0.1, 0.2, 0.5 is radius of circle, (Ox, Oy) = (2.5, 2.5) is the center of the circle, θ is angular variable 0-360 degree. The results indicated that the circular interpolation position is automatically controlled. However, accuracy at inflection points (θ= 0, 90, 180, 270 degree) is lower. The circularities of about 6-10 nm are observed from Fig.3.

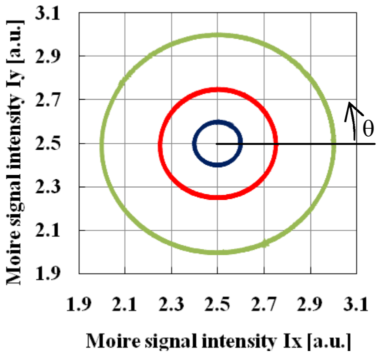


Figure 3: Results of circular interpolation position automatic control

4 Concluding Remarks

The non-contact micro-nano biaxial position sensor based on moiré interference phenomena was proposed. The position control is done to an arbitrary position by PI control, and the positioning accuracy at the positioning point are the standard deviation 0.07nm (X-axis) and 0.23nm (Y-axis) are estimated.

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References:

[1] S. Hattori, et al., Bul. the Japan Society of Precision Eng. 20, 2 (1986)73-78.
[2] H. Zhou, et al., J. Vac. Sci. Technol. B12, 3261(1994)
[3] E. E. Moon, Ph.D. Thesis, MIT (2004)
[4] B. Choi, et. al., J. Opt. A, Pure Appl. Opt.9, 1087-1094 (2007)
[5] T. Higuchi, et. al., EUSPEN Conf. Proc., Vol.1, 258-261 (2010)
[6] Y. Uchida, et. al., EUSPEN Conf. Proc., Vol.1, 224-227 (2009)