Concurrent measurement method of spindle radial, axial and angular motions using concentric grating interferometers

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This paper describes a novel method for measurement spindle radial, axial and angular motions using concentric circle grating interferometer. In the method, a concentric circle grating with fine pitch is installed on the top of the spindle of interest. The concentric circle grating is used as a reference artifact in the method. Three optical sensors consist of a laser as a light source, and two interferometers. The first interferometer observes an interference fringe between a reflection light from a fixed mirror and the 0-order diffraction light from the grating for vertical displacement measurement. The second interferometer observes an interference fringe between the ±1-order diffraction light from the grating for lateral displacement measurement. Using three optical sensors, three vertical displacements and three lateral displacements of the grating can be measured. From these measured displacements, radial, axial and angular motions of the grating, i.e. the spindle, can be calculated concurrently.

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1. Introduction

A conventional spindle measurement has contributions from the spindle motion error and the form error of the target artifact. In the conventional methods to measure radial, axial and angular motions, complicated artifacts and displacement sensors are required. The concurrent measurement of radial, axial and angular motions can be realized using the reference artifact of two spheres linked with a bar [1]. The use of the concentric circle grating has been proposed to measure spindle radial motion error by the other researchers [2, 3].

In a novel method for the concurrent measurement of five degrees of freedom spindle motion errors (=radial (2 degrees) + axial (1 degree) + angular (2 degrees)) using concentric grating interferometers, a concentric circle grating is installed on top of the spindle of interest ,and it is used as the reference artifact. Three optical sensors are fixed above the concentric circle grating to observe the proper position of the grating. Because the concentric circle grating is not voluminous and not heavy, this method is effective for any spindle, and does not affect the spindle original rotational motion. Moreover, this method is suitable for maintaining the traceability against the meter definition because it uses laser interferometers.

2. Measurement principle

The basic principle of the proposed measurement method is shown in Fig.1. A concentric circle grating is set on the top side of the spindle of interest. Three optical sensors, A, B and C in the figure are fixed over the concentric circle grating, and observe the proper positions of the grating. The spindle rotation center must be almost aligned to the center of the concentric circle grating. In the figure, we assumed that the origin point is almost located at the center. The optical sensor A is set on the line along Y-axis, the optical sensors B and C are set on the line along X-axis. The optical sensor consists of a laser as a light source and two interferometers. The configuration of the optical sensor is shown in Fig.2. One interferometer observes an interference fringe between a reflection light form a fixed mirror (FM) and the 0-th order diffraction light from the grating for vertical displacement measurement. Another interferometer observes an interference fringe between the +1st and -1st order diffraction lights from the grating for lateral displacement measurement.

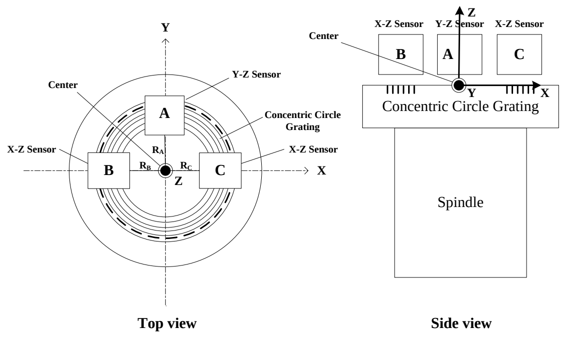

Fig.1 Basic principle of spindle motion errors measurement

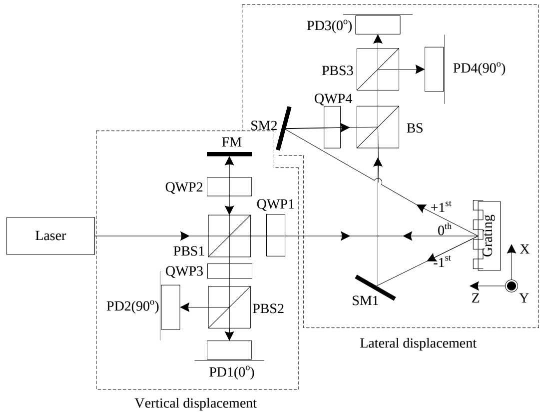

Fig.2 Schematic diagram of the optical sensor

In Fig.2, the output signals (I_{PD1}, I_{PD2}, I_{PD3} and I_{PD4}) from photo diode PD1, PD2, PD3 and PD4 can be expressed as follows,

$$I_{PD1} = E_{fix}^2 + E_0^2 + 2E_{fix}E_0 \cos\left(\frac{4\pi}{\lambda}\Delta z\right) \quad (1), \qquad I_{PD2} = E_{fix}^2 + E_0^2 + 2E_{fix}E_0 \sin\left(\frac{4\pi}{\lambda}\Delta z\right) \quad (2),$$

$$I_{PD3} = E_{+1}^2 + E_{-1}^2 + 2E_{+1}E_{-1} \cos\left(\frac{4\pi}{d}\Delta x\right) \quad (3), \qquad I_{PD4} = E_{+1}^2 + E_{-1}^2 + 2E_{+1}E_{-1} \sin\left(\frac{4\pi}{d}\Delta x\right) \quad (4),$$

where; E_{fix} and E_0 is the amplitude of the light reflected from FM and the grating electrical field, E_{+1} and E_{-1} is the amplitude of $\pm 1^{st}$-order diffraction electrical field, Δx and Δz is the displacement shift of the grating along the X-axis and Z-axis, d is the grating pitch and λ is the wavelength of the light source, respectively.

3. Preliminary experiment and discussion

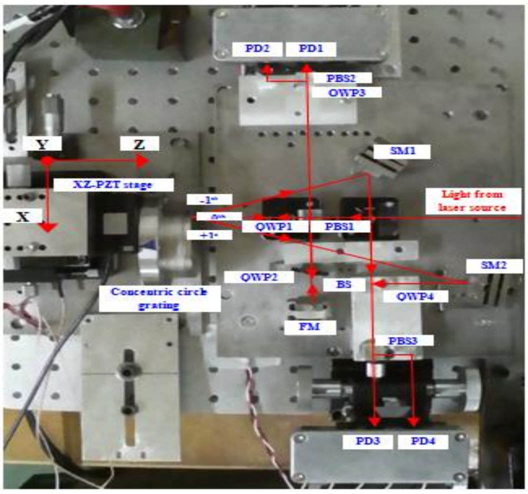

Fig.3 Experimental setup

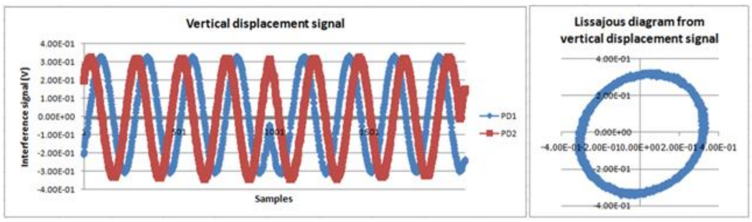

Fig.4 Interference signal and Lissajous diagram from vertical displacement

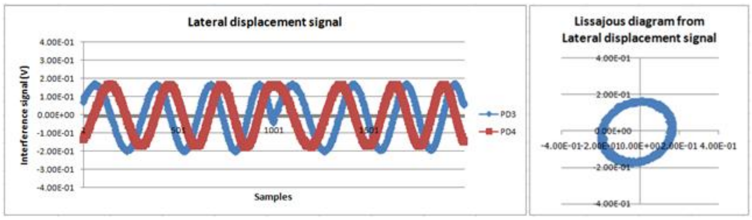

Fig.5 Interference signal and Lissajous diagram from lateral displacement

In order to confirm the equation (1) - (4), we constructed the grating interferometer as shown in Fig.3. In the experiment, the concentric circle grating was set on the XZ axes PZT stage. A He-Ne laser was applied to the interferometer as a light source. Photodiodes PD1 and PD2 were detected the interference signal of vertical displacement when PZT was moved along the Z-axis, and photodiodes PD3 and PD4 were detected the interference signal of lateral displacement when PZT was moved along the X-axis, respectively. Fig.4 and Fig.5 show the interference signal and Lissajous diagram of vertical and lateral displacements.

The experiment results show that this method can measure the displacement of the grating with nanometer resolution by using fringe interpolation. We can apply vertical and lateral displacements of three optical sensors for measurement radial, axial and angular motions of the spindle.

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