Displacement sensor by a common-path interferometer

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Introduction

In manufacturing process technologies, high-precise displacement measurements are one of the key requirements for upgrading of these technologies. For the high-precise displacement measurements, the use of an interferometer such as Twyman-Green is a common practice. However, the interferometers are affected by air turbulence.

A position sensing-grating (PSG) interferometer for a specular object was proposed in order to solve this problem.1) The PSG interferometer is a common-path interferometer. The setting for sensing is simple and analysis of the fringe pattern is easy. However, the aberrations of the focusing lens cause measurement error. Therefore, the analysis of measurement error considering the aberration of the lens was carried out and an optics configuration that canceled the aberration was determined. 2) However, the problem of diffraction efficiency has not yet been solved.

In this paper, an improved common path interferometer is proposed to measure the displacement of a specular object. The proposed interferometer is based on the PSG interferometer but has no diffraction grating. The analysis method of interference fringes analysis for more precise is also described.

Displacement sensor

Figure 1 shows a schematic of the proposed interferometer. The interferometer consists of the beam splitter, the focusing lens and the plane mirror. The specular object is placed at the focus of the focusing lens in the interferometer. A schematic of the optical path is shown in Fig. 2. The incident light is divided into clockwise light and counterclockwise light by the beam splitter. Both types of light propagate in almost the same space in the interferometer. Therefore, the air disturbance dose not influence the measurement. In the interferometer, interference fringes are null fringes when there is no aberration of the focusing lens and the specular object is placed at the focus of the focusing lens. When the specular object is moved in the direction of
the z axis, the interference fringes become straight lines with equal intervals. As both optical paths in the interferometer are symmetrical, only the effect of a coma aberration contributes to the formation of the interference fringe, even if there are many other aberrations in the focusing lens. The interval narrows in proportion to an absolute value of the displacement of the specular object. Figure 3 shows interference fringes obtained by the proposed interferometer.

**Analysis method of interference fringe**

When the specular object is close to the focus of the focusing lens, there is a region where the number of interference fringes is less than one and it is possible to measure precisely a small displacement by analyzing the intensity of the interference fringe. The analysis of the interference fringe is carried out by integrating the intensity over the region where the interference fringe is obtained. A photodetector is used to integrate the intensity of the interference fringe. By acquiring the intensity with the photodetector, information of the interference fringe is converted into the displacement signal without the use of a computer. When the specular object is placed at the focus of the focusing lens in the interferometer, the interference fringe becomes null and the voltage of the displacement signal obtained by the photodetector is minimum. When one interference fringe is formed on the photodetector, the voltage of the displacement signal is maximum.

The relationship between the displacement of the specular object and displacement signal was simulated from the amount of coma aberrations of the focusing lens. A result of the simulation is shown in Fig. 4. The simulation was carried out under the following conditions: The wavelength and the diameter of the light source were 633 nm and 10 mm, respectively. The focal length of the focusing lens was 300 mm. The interval of the light on the lens was 80 mm.

**Experimental results**

The experiments were carried out in order to confirm the validity of the proposed interferometer. In the interferometer, the numerical aperture of the focusing lens was 0.25 and the light source was a He-Ne laser with a wavelength of 633 nm. In the experiments, the voltage of the displacement signal obtained by the photodetector was 6.49 V when the displacement of 50 µm was given. Therefore, the sensitivity was 7.7 nm/mV. When the mirror was displaced by 10 nm step, the displacement was detected by the proposed interferometer. Figure 5 shows the displacement signal obtained by the proposed interferometer.

**Conclusions**

In this paper, a simple common path interferometer was proposed to measure the displacement of a specular object. The analysis method of the interference fringe was also described. When the displacement of 10 nm was given, the displacement was measured by the proposed interferometer and the fringe analysis method.
Fig. 1 Schematic of the displacement sensor

Fig. 2 Schematic of the optical path

Fig.3 Interferograms obtained by the proposed interferometer in displacement z of a specular object; (a) z=-0.2mm, (b) z=-0.1mm, (c) z=0.0mm, (d) z=0.1mm, (e) z=0.2mm
Fig. 4 Optical intensity integrated over the aperture of the sensor

Fig. 5 Photograph of the proposed interferometer
**Fig. 6 Waveform of signal obtained by the proposed interferometer**

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**References**