An optical head with Littrow configuration for measurement of the pitch deviation of a diffraction grating

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A method of measuring the pitch deviation of a diffraction grating by using the positive and negative diffracted beams is a promising one. Meanwhile, the conventional theory cannot measure the pitch deviation of a diffraction grating with a nominal pitch narrower than the light wavelength of the laser beam to be projected onto the grating. In this paper, a new optical setup is designed and developed to extend the principle. In the setup, laser autocollimation units are employed to detect the angle of diffraction of the first-order diffracted beam and the reflected beam in the Littrow configuration. Through the arithmetic operation, the pitch deviation can be evaluated while effectively reducing the influences of angular error motion of a scanning and the local slope of a diffraction grating.

Laser interferometers and optical linear encoders with high resolution are widely employed for ultra-precision positioning in the sub-μm class. Optical linear encoders are gaining market share, especially in terms of cost and environmental robustness (Kunzmann et al., CIRP Ann. Manuf. Technol., 1993). Ensuring the accuracy of the diffraction scale grating is crucial for maintaining the measurement accuracy of the linear encoder. Conventional methods for evaluating scale gratings include scanning electron microscopy, atomic force microscopy, and linear scale comparators. However, these methods have drawbacks such as a limited measurement area and the requirement for precise environmental control. Therefore, it is desired to establish a method to evaluate pitch variation quickly and accurately, even in laboratories and processing sites with limited budgets and equipment. Against this background, a method has been proposed to evaluate the pitch deviation of scale gratings by simultaneously capturing the changes in angles of diffraction of the positive and negative first-order diffracted beams associated with changes in the pitch deviation of the scale using a laser autocollimation system (Quan et al., Precis. Eng., 2021). This method can detect pitch deviations without being affected by angular motion errors during scale scanning and the local slope of the scale. However, when the grating pitch is smaller than the laser wavelength, the first-order diffracted beams cannot be obtained simultaneously, and the grating pitch deviation evaluation method cannot be applied.

In this paper, we attempt a theoretical extension of the measurement method of the pitch deviation. In the previous study, the measurement laser beam was projected perpendicularly onto the scale grating. In the extended principle, the laser beam is incident obliquely to the scale grating to obtain a diffracted beam. The first-order diffracted beam and reflected beam are captured by a pair of laser autocollimation units so that the evaluation of pitch deviation can isolate the influences of angular motion error and the local slope of the scale through arithmetic operations. In this paper, the results of experimental verification of the feasibility of the proposed correction theory by designing and constructing a prototype correction optical system based on the proposed correction principle are reported.