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An Optical Measurement Technique for Dynamic Stiffness and Damping of Precision Spindle System

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Abstract

The dimensional measurement technique utilizing curved-edge diffraction is applied for the dynamic system identification of precision spindle system. Both static and dynamic behavior including stiffness, damping ratio, and parasitic motion of a precision ball bearing spindle system is characterized by impact response, while the spindle displacement is measured with the curved-edge-type sensors (CES). The CES effects of spindle radius and surface quality were theoretically and empirically investigated. The capacitive-type sensors (CS) were used for a baseline comparison with the CES outputs. Unlike CS, CES is not sensitive to the spindle radius, surface quality, and coupling motions, shows high bandwidth and low noise, and allows for the dimensional measurement at a localized area. These results indicate that CES can be a good alternative to CS for spindle metrology. In the experiment, natural frequency (56 Hz (linear) and 680 Hz (angular)), stiffness (460~790 N/μm) and damping ratio (0.04~0.08) of precision spindle system were measured by CS and CES at the same time. The dynamic model of ball bearing spindle system was also discussed.

Keyword: Spindle metrology; Curved edge sensor; Edge diffraction; System identification

1. Introduction

Precision ball bearing, hydrostatic or aerostatic spindles represent a key part of machine tools because they determine the quality of the final product produced and the overall manufacturing productivity and efficiency. Therefore, dynamic system identification and condition monitoring of precision spindles is a key factor in increasing the availability of the machine tool and achieving a more robust machining process [1-4]. Precision spindle metrology, i.e., utilizing a cylindrical or spherical target artifact with non-contact sensors to measure a machine tool spindle's "axis of rotation" errors, including radial, axial, and tilt errors, is basic science and technology for sustainable manufacturing [5,6].

Significant research has been devoted to the development of measurement and analysis techniques of precision spindles. Currently, a few approaches in measuring and evaluating precision spindle systems by using capacitive-type sensors (CS) or eddy current-type sensors (ECS) exist [7,8]. However, these sensors are typically designed for flat target surface measurement. CS and ECS are the most commonly used in spindle measurements. It is standard practice for commercial CS and ECS to be factory calibrated with flat-target surfaces. Because the probes are calibrated to a flat target, measuring a target with a curved surface will cause errors. Because the probe will measure the average distance to the target, the gap at zero volts will be different than when the system was calibrated [9,10]. From the previous work [11,12], the CS shows spindle radius effects on the displacement measurement. As depicted in Figure 1, errors will also be