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Simultaneous dual-axis error measurement and corresponding compensations

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Abstract
A novel measurement system for the cross-sectional profile has been proposed in this study. It can be employed to inspect the cross-sectional profile for the machine tool during the simultaneous motion of the linear and the rotary axis. The system consists of two measurement modules for determining the linear positioning and the angular indexing error respectively. In the measurement module of the linear axis, it is based on the common path structure of Fabry-Pérot interferometer (FPI) and the optical cavity is composed of a plane mirror and corner cube retro-reflector (CCR). The phase shift is induced by the one-eighth waveplate in the cavity, and then the orthogonal signal can be detected by two photodiodes. Hence the measurement of the linear displacement can be achieved. In the other module, the alignment mechanism for the rotary encoder has been developed to adjust the rotary encoder and the rotary axis for testing to be the coaxial state. Therefore, the installation time of 70% can be reduced by the utilization of the alignment mechanism and the angular error can be measured by this module. By the integration of these two measurement modules, the measurement of the cross-sectional profile can be realized. From the measurement result of the contour error, errors during the increasing, the decreasing and the constant motion are enhanced 35 µm, 18 µm and 3 µm error compensation of the linear and rotary axis. The proposed measurement system can be employed of the cross-sectional profile measurement of a ground part, e.g., the internal and external cylindrical grinding machine or the grinding and milling machine for evaluating the performance of the manufacturing. Furthermore, this system possesses the features of the compact design and the convenient inspection.

contour error, dynamic simultaneous measurement, Fabry-Pérot interferometer, rotary encoder, linear axis, rotary axis

1. Introduction

In the precision mechanical and the semiconductor industries, the positioning accuracy and the repeatability are as important parameters for evaluating the performance of the machine tools and above-mentioned parameters must be inspected by such high precision instrument. And then the calibration procedure should be carried out to improve the quality of the production of the machine tool. Therefore, precision measurement technology has become a critical issue of industrial development.

Laser interferometers possess measurement characteristics of high resolution, large measuring range and the measurement result provides the direct traceability to the definition of the meter, so interferometers have been commonly applied in the calibration of the linear positioning error in machine tools [1-4]. In contrast to the non-common path structure of the Michelson interferometer, FPI is a common path structure and there is no additional beam splitter in the optical cavity. It means that all measurement beams transmit in the same path [5-7]. In comparison with the optical structure between FPI and Michelson interferometer, FPI is more stable for industrial utilization and the environmental disturbances (thermal expansion, vibration) will be significantly reduced in this structure [8]. Moreover, the proposed measurement module of the linear axis is based on the common path FPI to carry out the calibration procedure of the machine tool.

A rotary encoder is a common measurement tool for the inspection of the rotary indexing error. It is based on the diffraction principle to determine the angular value. In order to enhance the measurement accuracy, the adjustment including the eccentric, pitch and yaw error between the rotary axis for testing and the rotary encoder must be under the allowable range. In this investigation, an alignment mechanism is developed to adjust lateral displacement, pitch and yaw angle of the rotary encoder and then the above-mentioned error between it and the rotary axis for testing can be minimized. Therefore, assembly efficiency and alignment accuracy will be improved obviously.

From the summarization of the above-mentioned descriptions, the FPI and the rotary encoder are utilized to construct the measurement module of the linear and the rotary axis respectively. By the integration of two measurement modules, the linear positioning error and angular indexing error can be inspected simultaneously. And by the analysis of the cross-sectional profile, the performance of the machine tool can be evaluated [9-11].

2. Measurement system for cross-sectional profile

The measurement system of the cross-sectional profile with the integration of two modules has been constructed shown in Fig. 1. By the connection with the signal acquisition card, the self-development measurement program and two modules, the actual measured values of linear and rotary axes can be obtained simultaneously to estimate the cross-sectional profile of dual-axes. The measurement data will be acquired in the experimental process and the measuring cycle will be continued until the measuring time is beyond the set value. And then the measured data will be analyzed and revealed.

2.1 Measurement module for linear axis

The folded FPI consists of three chief units including the laser light source, the sensor head and the signal processing unit (Fig. 1). The laser light source (stabilized He-Ne laser) passes through the isolator, fiber coupler, mirror and the BS to the optical cavity which composed of the plane mirror and CCR. The one-eighth waveplate is placed in the optical cavity and give rise to the phase shift between the laser beams. When the lights emerging from the optical cavity and interference with each other, it will be reflected to the PBS and then the divided signal will be acquired by two photodetectors. To improve the reliability of the measurement signal, the pre-amplifier for two channels is constructed in the sensor head unit. And from the pre-amplifier, the signal is transmitted to the signal processing unit which consists of DC offset and auto gain control compensation circuits to enhance the stability of counting.

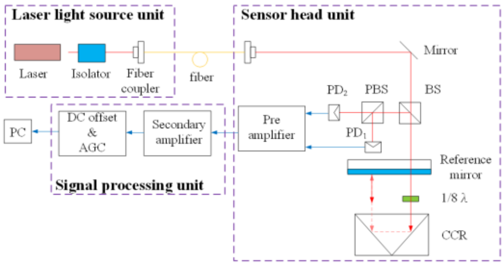


Figure 1. Optical design of the folded FPI

2.2 Measurement module for rotary axis

In this study, an alignment mechanism (Fig. 2) for the rotary encoder is developed which enables to adjust the eccentricity and angle (pitch, yaw) of the ring axis. In the adjustment of the eccentricity, the design of the dovetail groove is proposed. By utilization of three dovetail grooves and two fine adjustment screws, the lateral displacement including the horizontal and vertical direction of the ring can be realized accurately. And in the adjustment of the angle, a ball, springs and fine adjustment screws are employed between two fixtures to determine the pitch and yaw angle. After the adjustment procedure for the rotary encoder, two lateral displacements can be reduced to ±15 µm and the angular error is improved to 10 µm. Therefore, the designed mechanism is beneficial for enhancing measurement accuracy and reducing the adjustment time.

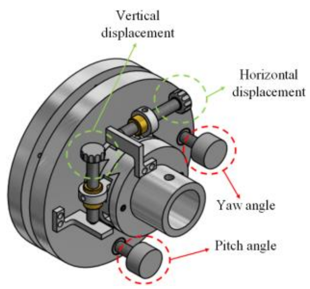
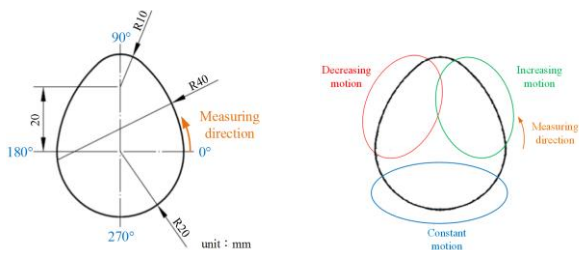


Figure 2. Alignment mechanism for the rotary encoder

3. Measurement result and analysis

A track of cam indicated in Fig. 3-(a) is designed with a base circle which possesses the diameter of 40 mm to simulate the cross-sectional profile produced by the simultaneous motion of dual-axes. According to the measurement direction of the cross-section profile (Fig. 3-(b)), the track can be divided into three parts, one is the increasing motion, another is the decreasing motion and the other is the constant motion.



(a) Track of cam (b) Different motion part

Figure 3. Cross-sectional profile

By the difference between the ideal and the measured curve, the contour error of dual-axes during the simultaneous motion can be acquired. The contour error with and without compensation is shown in Fig. 4. Analysis for each part of the error is as the following description.

In the part of the increasing motion, it can be observed that the positioning error gradually increases caused by the error accumulation. In the part of the decreasing motion, because of the backlash produced by the reverse rotation, there is a gap between the increasing and the decreasing motion. In the part of the constant motion, because the radius of the cam in this part keeps a certain value, the change of the error is small relatively. After the error compensation to the controller, the contour error is improved in the increasing and the decreasing motion and the gap between two motions caused by the backlash is significantly reduced. The analysis of the measurement result is presented in Table 1. From the measurement result of the contour error, errors during the increasing, the decreasing and the constant motion are enhanced 35 µm, 18 µm and 3 µm.

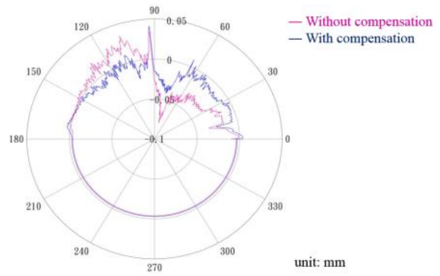


Figure 4. Comparison results of the contour error

Table 1 Comparison results of the contour error

Contour error		(unit: µm)	
Motion	Without compensation	With compensation	Improved value
Increasing	45	10	35
Decreasing	26	8	18
Constant	8	5	3

4. Conclusions

In this study, a novel measurement system is developed for measuring the cross-sectional profile by integrating two modules including the linear and the rotary axis. The measurement module of the linear axis is based on the common path structure of the FPI which is insensitive to the environmental disturbances. Therefore, the high precision measurement can be achieved. In the measurement module of the rotary axis, a compact alignment mechanism which enables to adjust the lateral displacement, pitch and yaw angle of the rotary encoder is designed. By these two modules, the cross-sectional profile during the dual-axes motion can be acquired. And the contour error can be obtained by the difference between the ideal and the measured curve. Consequently, the constructed measurement system is beneficial for the estimation of the performance of the machine tool, e.g., the internal and external cylindrical grinding machine or grinding and milling machine for industrial application. According to the error compensation, the contour errors during the increasing, decreasing and constant motion are improved 35 µm, 18 µm and 3 µm.

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