The development of a multi-degree-of-freedom rotary table tested system

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Precision rotary table is a very important actuator in many industries, but most rotary table calibration only tests 1 or 2 degree of freedom errors. Therefore, a multi-degree-of-freedom measurement system for rotary table test was established in this paper. This system can test the multi-degree-of-freedom errors of a rotary table for 360 degree. This measurement system consists of a laser diode array, and 3 2-dimensional position sensing detectors. The laser array was assembled by 12 laser diodes witches were mounded around a circular fixture and they were mounted on the rotary table. The 3 position detectors were fixed and around the rotary table. In this system, 3 laser diodes project 3 laser rays onto the 3 PSD at one time. From the 3 position sensing detectors, 6 channel analog signals can be acquired continuously by a 16 bits A/D card and a personal computer. To analysis the 6 signals of position sensing detector, the multi-degree-of-freedom errors of rotary table can be carried out. The relationship between the multi-degree-of-freedom errors and the signal of position sensing detector was derived by modeling the optical model of this measurement system. In this paper, the PSD calibration, measurement system verification, measurement system stability test were completed. And the rotary table repeatability test was implemented on a motorized rotary table. Form the above test, the linear and angular accuracy are about 2 μm and 1 arc sec separately.

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1. Introduction

Angle measurement is very important in the measurement of precision machines. The conventional instruments include the rotary encoder, laser interferometer, autocollimator and precision level. A rotary encoder [1] is commonly used in indexing measurement in a rotary machine, e.g. the spindle of machine tools and the indexing of a ball screw. But, the rotary encoder does not suit inclination measurement and geometric errors in machine tools. The laser interferometer [2] can be used to measure small angle and machine tools' geometric errors, but its setting up is difficult and it can measure only one kind of geometric error each time. It requires a great deal of time for all a machine tools geometric errors to be measured. The autocollimator [3] is frequently used to measure small angle and machine tools' geometric errors, and it can be applied to two dimensional angle measurement (pitch error and yaw error), but its disadvantage is that it is difficult to set up. The conventional inclination measurement system uses a precision level [4].

Some research focuses on multi degree of freedom measurement which is combination of the linear translation measurement and angular translation measurement, they are most focus on spindle [7], the rigid body [8], a translation stage [9][10]. The multi DOF indexing table measurement or rotary table measurement is few because most measuring range of angle measurement system is small. In 2005, Jywe and Chen [11] established a 4 degree of freedom rotary table measurement system by grating, laser diode and position sensing detector. In 2007, Chen, Lin and Jywe[12] again build a 6 DOF rotary table measurement system using a pyramid-polygon-mirror, 3 PSDs and 3 laser diodes. But this system needs a pyramid-polygon-mirror which is hard to fabricate and expensive, although it can measurement 6 DOF error for rotary table.

In general, the rotary table includes the index error, wobble error and eccentricity. But conventional rotary table calibration techniques (laser interferometer or autocollimator) only calibrate the index error and the wobble error. However, the high precision rotary table must be calibrated in more details. Through the complete rotary table calibration, the errors of rotary table can be compensated. In this paper, the errors of rotary table were defined by 6 DOF, i.e. three linear position errors (δ_x , δ_y , δ_z) and three angular position errors (ε_x , ε_y , ε_z). The index error was represented by ε_z , the wobble error was represented by ε_x and ε_y , the eccentricity was represented by δ_x and δ_y .

This paper builds a 6 DOF measurement system by 12 laser diode, 3 PSDs and some fixtures. It doesn't require expansive and very precision article reference component. It can test the rotary table for a 360° full circle.

2. System structure and model

The schematic diagram of this presented measurement system is shown in the Fig.1. In general, 1 2-dimensional position sensing detector (PSD) can resolve 2 degree of freedom errors. This presented measurement system use 3 PSDs to measure the 6 degree of freedom errors. If the PSD is only used on the angle measurement, the ratio between the rotary table rotation and the variation of laser spot on the PSD is fixed. When the rotation angle is fixed, the variation of laser spot on the PSD will increase if the distance between the PSD and laser is increase. Therefore, the angle resolution can be increase by increase the distance between the laser and PSD. However, the this presented measurement system not only measure the rotation angle of table but also measure other 5 degree of freedom errors. In general, a rigid body in 3-D space has 6 degrees of freedom, i.e. three translational along the x, y and z axis directions, respectively, and three angular motions as the body rotates about the x, y and z axes. Consequently, use mathematic method to model the measurement system is necessary. It will describe in the subsequent section.

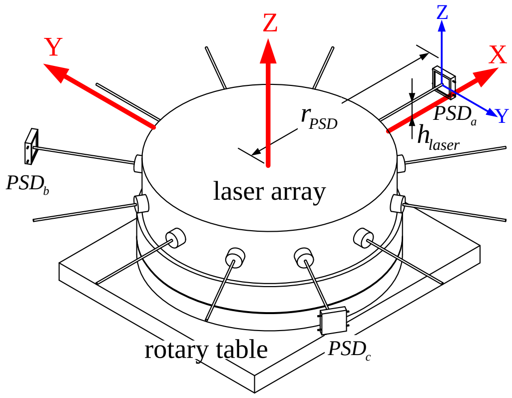

Fig. 1 Schematic diagram of the presented measurement system.

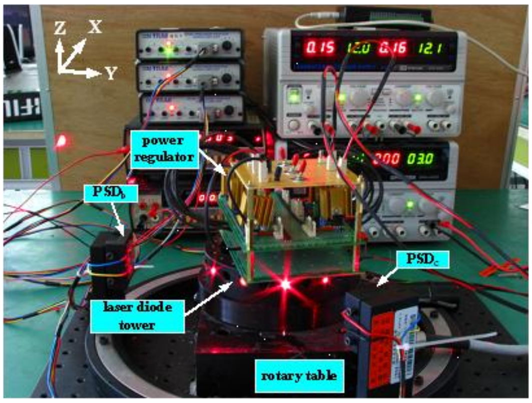

Fig. 2 Photograph of the verification of ε_z

4. Conclusions

This paper completes a 6 degree of freedom errors measurement for rotary table. It consists of 1 laser array, 3 PSDs and a system fixture and it can used to measure the 6 DOF errors of rotary table or indexing table for a full circle. It is a low cost solution for 6 DOF rotary table per formance test because it doesn't require any article part or reference indexing table. This paper used the skew-ray tracing method to build the mathematic optical model. In this paper, the model has verified by system verification test. The PSD calibration, system verification and system stability test were completed. Its linear and angular accuracy are about 1 μm and 1 arc sec respectively.

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