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Development of the principle for the angle measurement using the two-track scale

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Abstract
Our study aims to develop the miniaturization angle measurement device applied to a principle of the super high accurate angular measurement.
A rotary table requires a rotational positioning with high accuracy, for example, processing a material on a rotary table like a machining center. It is necessary to measure the angle indicated by the rotary table due to control this positioning. The angle accuracy of the rotary table is generally determined by a rotary encoder installed on it. The rotary encoder is one of the angle measurement devices, and it is important to improve the performance of the rotary encoder for the rotational positioning with high accuracy.
There are two methods to improve the angle accuracy of the rotary encoder. One method is the way to decrease the angle error directly using the high-performance parts constructing the rotary encoder. The other method is self-calibration to detect and correct the angle error by itself. These methods realize the angle accuracy 0.1 to 0.4 [arcsec] in the one rotation. However, it is limited to improve the angle accuracy using these methods.
Therefore, we proposed the new principle which can realize the angle accuracy 0.01 [arcsec] without these methods, the super high accurate angular measurement principle, and developed the angle measurement device based on this new principle. However, on the theory of new principle, the device had the problem that its size grows up due to use the two rotary encoders.
Therefore, we propose the principle of the super high accurate angular measurement to apply to the miniaturization angle measurement device installed the special scale disk in this paper. This scale is consisted of two-track scale lines of which the pitches are different.

Keywords: Angle, Rotary Encoder, Measurement instrument, Index table

1. Introduction

A rotary encoder can measure the full range of angles (0-360°) and is used for controlling the rotation position of a shaft. Therefore, it is important to measure the angle with high accuracy using the rotary encoder. In previous studies, the performance of the rotary encoder has been improved by two methods. One method is direct reduction of the angle error factors such as runout of the main shaft and the eccentricity between the center of the main shaft and the scale disk using the high-performance parts of the rotary encoder. The other method is self-calibration that detects and self-corrects the angle error. The angle accuracy of these methods has been achieved in 0.1 to 0.4 arecsecs [1,2].

An index table is one of the rotary tables incorporated with the rotary encoder and controls the static angle position of the rotary table, which is built into a machining tool like a machinig center. Its main function is to fix the angle position indicated by the rotary table. The National Institute of Advanced Industrial Science and Technology (NMIJ/AIST) in Japan has developed a high accurate angular measurement apparatus without the above two methods [3]. This apparatus is applied with an angular indexing principle using two rotary encoders and the circle closure characteristic of the angle error. Moreover, the angle accuracy of this apparatus expects to be less than 0.01 arcsec [4]. However, this apparatus has a problem that its size increases because it uses two rotary encoders. Therefore, our study proposes a method to decrease the size of the apparatus.

2. Apparatus

2.1. The previous version

Figure 1 shows the apparatus developed by AIST. This apparatus consists of the follows: a motor, two independent shafts (Index shaft and Motor shaft), two scale disks (Scale A and Scale B) with the same total scale lines and the sensor units to read two scale disks.

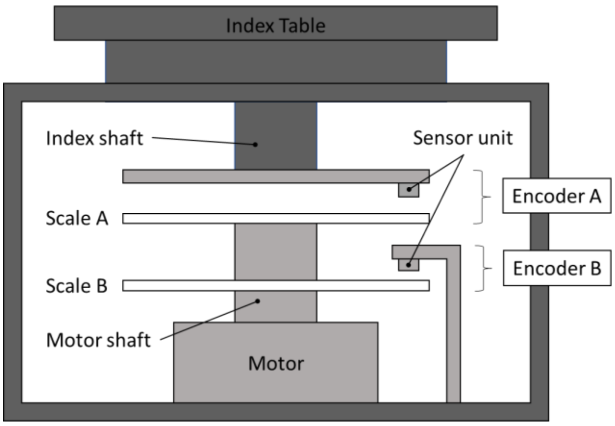

Figure 1. the apparatus developed by AIST

Encoder B consists of Scale B and the sensor unit attached to the housing of the apparatus. While, Encoder A also consists of Scale A and the sensor unit attached to the index shaft which extends below the index table. As indicated in figure 1, the sensor units of Encoder A are indexed and rotate in synchrony with the indexing angle of the index table. Moreover, Encoder A outputs the angle signals triggered by Encoder B's original signal.

2.2. Proposal apparatus model

Figure 2 shows the model of a miniaturization apparatus. The difference of two apparatuses is using a special scale disk as shown in figure 3 rather than two rotary encoders. The apparatus as shown in figure 2 also consists of the follows: a motor, two independent shafts, the special scale disk, and sensor units.

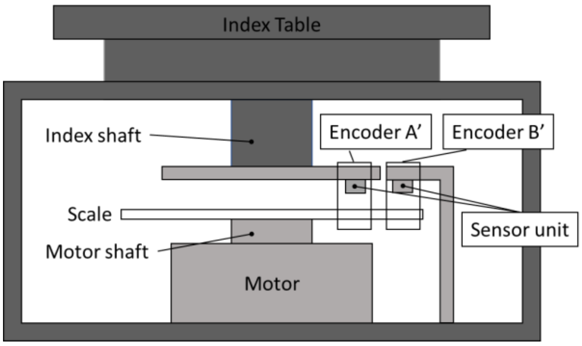

Figure 2. The model of a miniaturization apparatus

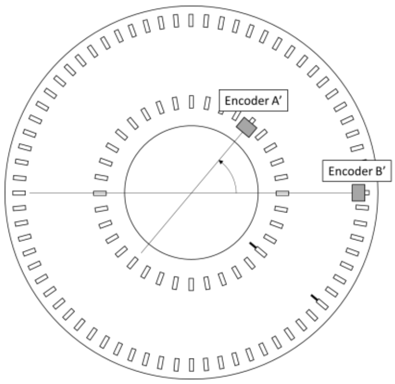

Figure 3. The special scale disk

The special scale disk attached by the motor shaft has two-tracks scale lines with the difference of the total scale line. Encoder A' consists of the sensor unit attached to the index shaft and outputs angle signals detecting the inside scale lines in the special scale after Encoder B' detects the own original signal. While, Encoder B' also consists of the sensor unit attached to the housing parts of the apparatus and outputs angle signals detecting the outside scale lines in the scale.

3. Principle and Experimental result

The principle is explained by two methods. In this time, the total scale lines in inner scale is N and in outer scale is $2N$.

(1) Taking the difference between the angle signal positions output by Encoder A' and Encoder B'.

(2) Taking the average to the difference values in (1) over the N scale lines.

In the method of (1), the difference is calculated by comparing the angle signals output by Encoder A' with Encoder B'. Then, Encoder B' outputs the angle signal being the frequency-divided to match the number of the angle signals output by Encoder A' in one rotation. Moreover, the difference values include the angle error and an offset. This offset is a small indexing angle that is higher resolution than the Encoder A'. In the method of (2), the averaged value becomes the offset because the angle error in the difference values become zero by the circle closure property. In other words, we can remove the angle error. Therefore, these methods can calculate the small indexing angle. Additionally, counting the scale lines in Encoder B' between the original signal outputs by Encoder A' and Encoder B', we can calculate the indexing angle with the Encoder A's resolution.

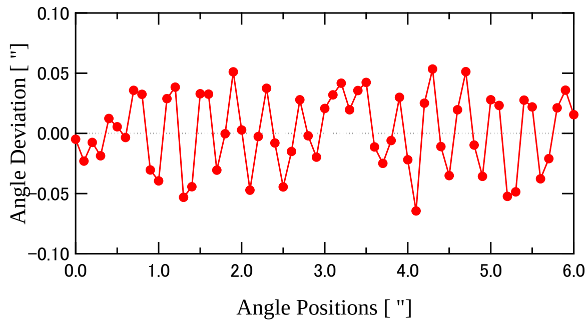

Figure 4. Experimental result

The experiment was carried out as follows: the measurement range is from 0 to 6 [arcsec], its steps is 0.1 [arcsec], the total scale line N is 9000. Moreover, the experiment was performed with a system in which the proposal apparatus without the index table was set on the previous apparatus. Figure 4 shows the experimental result. As indicated in figure 4, the horizontal axis is angle positions rotated by the index table and the vertical axis is the angle deviation between the measurement values of the proposal apparatus and previous apparatus. Additionally, the angle deviation is within 0.1 [arcsec]. As investigating the cause of the angle deviation within 0.1 [arcsec], the repeatability of the angle deviation is more than 0.1 [arcsec]. Therefore, the proposal apparatus is expected the angle accuracy less than 0.1 [arcsec] to improve the repeatability.

4. Conclusion

The National Institute of Advanced Industrial Science and Technology (NMIJ/AIST) in Japan has developed the angular indexing apparatus to measure the indexing angle of the index table with high accuracy. The apparatus expects to exceed 0.01 arcsec accuracy using two rotary encoders. However, the size of the apparatus is increasing. Therefore, we need to propose a method to decrease the size of the apparatus.

In this paper, we propose the miniaturization apparatus using a special scale disk. The result of comparing between the proposal apparatus and the previous apparatus, the angle accuracy of the proposal apparatus is within 0.1 [arcsec].

Acknowledgement

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References

[1] T.Masuda and M Kajitani 1993 High accuracy calibration system for angular encoders *J. Robot. Mechatron.* **5** 448-52.

[2] T Watanabe, H Fujimoto and T Masuda 2005 Self-calibratable rotary encoder, *J. Physics: Conference Series,* **13** 240-5.

[3] T Watanabe, and H Fujimoto 2006 High accuracy angle indexing table, *Proc. XVIII IMEKO World Congress*, Rio de Janeiro, Brazil.

[4] W Tyler Estler 1998 Uncertainty analysis for angle calibrations using circle closure, *J. Res. Natl. Inst. Stand. Technol.* **103** 141-51.