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Gear wheel magnetic rotary encoder with shaft run-out detection function

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Abstract

The gear wheel magnetic rotary encoder (GMR-Encoder) is used to control the rotation angle of the main spindle in lathes, grinding and milling machines because its price is low and its operation is stable even in dirty working environments such as water, oil and dust, also under shock and vibration.

The principle of the GMR-Encoder is that a magnetoresistive (MR) sensor detects a change in magnetic flux density generated by the rotating gear teeth disturbing an external magnetic field. It is possible to achieve high resolution 2^{23} by interpolating the pitch between the teeth ten thousand times.

We have been researching and developing technology to make this GMR-Encoder an angle sensor capable of outputting highly accurate angular signals. As a result, by using SelfA (Self-calibratable angle device) principle devised by National Institute of Advanced Industrial Science and Technology (AIST), the angular accuracy of GMR-Encoder is able to reach ±2" or less. This angular accuracy is not only equivalent to an optical rotary encoder but is also an accurate performance. Furthermore, this GMR-Encoder not only outputs angular position information, but also adds the ability to detect the rotational spindle runout of 1 µm. Continuous observation of changes in spindle runout is useful as information necessary for failure prediction and life management of machine tools.

In our presentation, we introduce the structure of a GMR-Encoder with high precision and runout detection function and explain the results of evaluation of its performance.

Rotary encoder, Self-Calibration, Run out, Gear wheel, Magnetoresistive sensor, Angle

1. Introduction

In this configuration of Fig. 1, this MR sensor detects magnetic flux density generated in the gap between a bias magnet and a magnetized gear wheel. If the magnetized gear moves in parallel with the MR sensor surface, the magnetic flux density on the MR sensor changes. The angle detection method is that the MR sensor generates a one cycle sin or cosine voltage changing signal for each gear tooth rotation. It is possible to achieve high resolution 2^{23} by interpolating the pitch between the teeth ten thousand times. In order to obtain a higher resolution angle division, MR sensor includes interpolator circuit that the electrical angle of a single gear tooth pitch is calculated by the arctangent of the Lissajous waveform of the sine and cosine voltages outputted from this MR sensor, and is divided to a high resolution digital signal. However, since the magnetic flux density is depended on the tip shape of the gear, non-uniformity of the pitch distance of the gear teeth and also non-uniformity of the gear tooth profile become angular error factors of the GMR-Encoder.

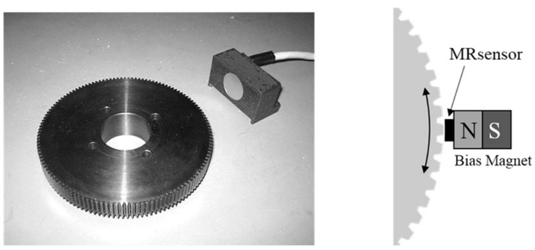

Figure 1. Gear-type Magnetic Rotary Encoder

In this paper, therefore, we introduce the GMR-Encoder which outputs the highly accurate angle signal by detecting the angular error inherent in the angle signal by the self-calibration method and performing self-correction.

2. SelfA Rotary Encoder

SelfA encoder [1,2] mechanism is very simple that several numbers of sensors are arranged around the gear at same angle interval as shown in Fig. 2. One arbitrary sensor is chosen as a main sensor. While rotating one round revolution, comparison measurement of the angle signal deviation $\delta_{(1,j),i}$ between a main sensor output and another sensor output is carried out. Finally, we can obtain a calibration curve by calculate the mean value μ_i of all $\delta_{i,j}$.

$$\delta_{(1,j),i} = A_{1,i} - A_{j,i} \tag{1}$$

$$\mu_i = \frac{1}{3}\sum_{j=1}^{3} \delta_{(1,j),i} = A_{1,i} - \frac{1}{3}\sum_{j=1}^{3} A_{j,i}\ , \tag{2}$$

Where, i (i = 1, 2, . . . , z) represent a gear teeth number, j (j = 1, 2, 3) is a sensor number. $A_{j,i}$ is an angle error of i-th gear position detected by j-th sensor. the mean value μ_i represents the calibration curve of rotary encoder, however it does not include 3n-th order Fourier components.

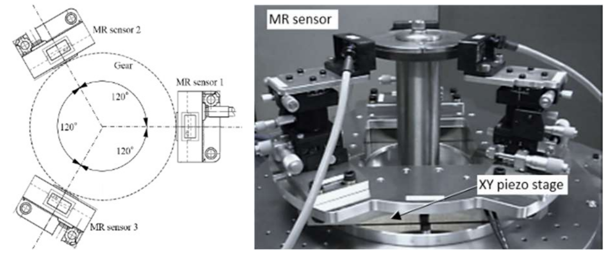

Figure 2. Configuration of SelfA type GMR-Encoder with three MR sensors. The MR sensor unit is installed on the XY piezo stage on top of the calibration apparatus.

2.1. Experiment and Results for SelfA of GMR-Encoder

We use the GMRE that has an involute tooth profiles, module M=0.4 and teeth number z=256, so that the gear diameter becomes 103 mm. The MR sensor TS5692 is manufactured by Tamagawa Seiki Co., Ltd. containing the MS-series semiconductor MR elements of Asahi Kasei Microdevices Corporation [4,5].

An experiment was carried out to compare between the angular error detected by self-calibration of the GMR-Encoder SelfA and the its angular error by the angle calibration apparatus shown in Fig. 2. The angular error of the GMR-Encoder before self-calibration obtained by the angle calibration apparatus is shown in Fig.3. The angular error corrected by the GMR-Encoder self-calibration is shown in Fig.4. The angular error of the GMR-Encoder is substantially corrected by self-calibration and improved to an accuracy of about ± 2 seconds. As a result of frequency analysis, it can be understood that the component of the angular error is approximately the 256n components, which is due to the division error of the electrical interpolation signal.

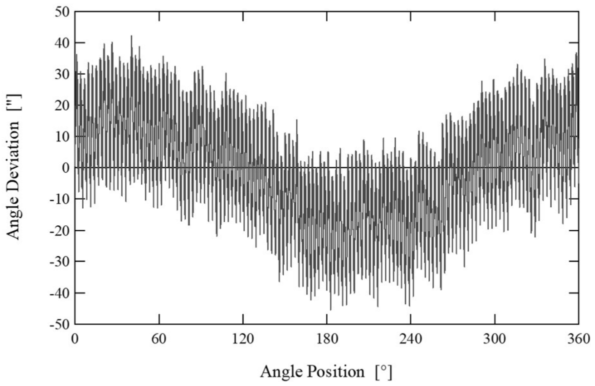

Figure 3. The angular error of the GMR-Encoder before self-calibration

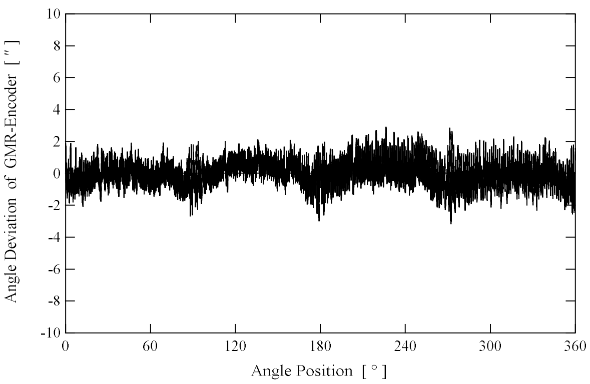

Figure 4. The angular error of the GMR-Encoder after self-calibration

3. SelfA⁺ Rotary Encoder

The angular error of the rotary encoder includes a rotational direction error caused by the graduation error of the encoder scale disc and the axial eccentricity of the scale disc, and translational direction error in the X-axis direction and the Y-axis direction caused by shaft runout. The principle of SelfA can detect this angular error. SelfA^{+} [3] is a principle that angular error can be divided into rotational direction error and translational direction error, and it is possible to quantitatively evaluate rotational axis runout. Generally, in order to detect runout of the rotating shaft, an external measuring instrument such as a capacitance sensor or a dial gauge is necessary. However, since the SelfA rotary encoder is installed in the device to control the rotation angle, it has an advantage that there is no spatial restriction like an external measuring instrument.

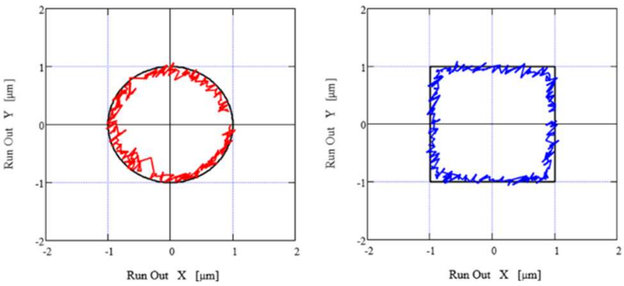

Figure 5. Runout detected by GMRE by SelfA+ principle. Left shows the Exp.setup 1, and Right shows the Exp. Setup

Fig. 5 shows the runout values detected by GMR-Encoder. The left and right figures in Fig. 5 show the runout values detected by the GMR-Encoder by SelfA^{+} analysis when a 2 μm diameter circular runout and a 2 μm square runout are generated respectively for three MR sensor heads using a XY piezo stage. The experimental system generates virtual shaft runout by vibrating the MR sensor unit. Therefore, the runout detected by the GMR-Encoder must take into account that in addition to the vibration generated by the piezo stage, an additional 0.03 μm vibration of the air bearing of the rotating shaft with gears is added.

The difference between the shaft runout applied by the piezo stage and the shaft runout detected by the GMR-Encoder was less than 1 μm, indicating that the GMR-Encoder was capable of detecting the shaft runout with high accuracy.

4. Conclusion

GMR-Encoder using MR sensor was proved to be able to detect angular error of ±2" or less and shaft axis runout with accuracy of 1 μm or less by using the principle of SelfA and SelfA^{+}. The ability of the GMR-Encoder to detect the shaft runout causing the failure of the equipment is expected to be useful for improving the efficiency of maintenance such as failure prediction.

References

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