euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
www.euspen.eu

Shaft run-out analysis by Gear-type Magnetic rotary encoder

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Abstract
It is difficult to use an expensive and high precision optical rotary encoder in an environment using a machine tool which cannot avoid the influence of water, oil, dust and vibration. For this reason, magnetic rotary encoders are generally used for machine tools. In particular, the gear type magnetic rotary encoder (GMR-Encoder) is a low-cost rotary encoder which makes use of magnetoresistive effect and easy to handle. Even if the gear teeth number is several hundreds, its resolution can be made high resolution by 1,000 to 10,000 times using electrical interpolation.
We have been researching and developing technology to make this GMR-Encoder an angle sensor capable of outputting highly accurate angle signals. As a result, the angular accuracy of GMR-Encoder was able to reach ± 10" or less by using SelfA (Self-calibratable angle device) principle. Furthermore, this GMR-Encoder not only outputs angular position information, but also makes it possible to add a function to detect the rotational shaft runout of the mounted spindle shaft. Continuous observation of changes in the amount of shaft runout is the information necessary for failure prediction and life management of machine tools.
In our presentation, we introduce the structure of a SelfA 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

Machine tools realize high degrees of freedom by multi-axis machining of 5-axis machining machines and multiple machining machines and realize machining of more complicated shapes. In recent years, in order to realize processing of large and complicated special curved surface shapes such as aircraft parts, automobile parts, molds, etc., and processing of a free curved surface shape such as an aspherical lens, "further improvement of machining accuracy" and "demand of failure prediction technology of machine tools, and of improvement of maintenance work efficiency" are rapidly increasing. Since the shaft runout causes the mechanical failure, damage and decreases in the precision of a machine having a rotating mechanism, the periodic inspection of the shaft runout is important in terms of safety and life management of the machine. The high accurate measuring devices such as a laser displacement gauge, a capacitance sensor and so on are used for measuring the shaft runout.

Magnetic encoders are widely used for spindle motors of machine tools since those are resistant to dust, dirt, oil and other harsh environments. In particular, the gear type magnetic rotary encoder (GMRE) is one of the magnetic rotary encoders which has a simple structure using a gear as a graduation disc and using a magnetoresistive (MR) sensor as a detector.

In this paper, we introduce a high-performance SelfA$^+$ [1] GMRE which added a function that can quantitatively detect rotational axis runout. The shaft runout detection function by the rotary encoder is realized by using the principle of SelfA$^+$ which is developed by National Institute of Advanced Industrial Science and Technology (AIST) in Japan, and which has been ordinary applied to optical rotary encoders.

2. SelfA and SelfA$^+$ Rotary Encoder

The SelfA [2,3] rotary encoder is an intelligent rotary encoder capable of detecting angular errors by installing several sensors at equiangular intervals around a encoder scale disc and analysing a difference in angle signals output from each sensor. As shown in Equation 1, 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 Self A can detect this angular error. SelfA$^+$ 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.

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

3. Experiment and Result

3.1. Gear-type Magnetic Rotary Encoder (GMRE)

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]. The sensing element material is a Sn doped single crystal film InSb. The MR sensor TS5692 interpolator circuit can make high resolution up to 16,384 times. Therefore, it is possible to output an angle signal of 2^{21}=8,192 division angular resolution by combining with the gear.

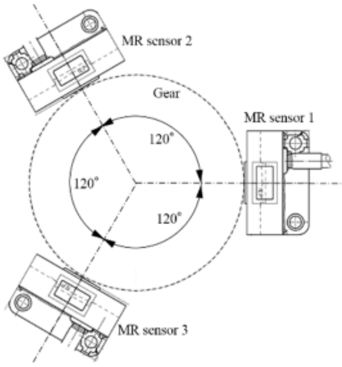

Figure 1. Configuration of SelfA type GMRE with three MR sensors

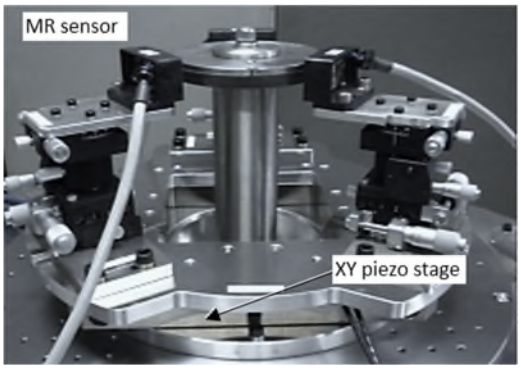

Figure 2. The MR sensors are installed on the XY piezo stage.

3.2. Experimental Setup

In order to experiment with SelfA⁺ rotary encoder by GMRE, three MR sensors were used as shown in Fig.1. Three sensors are installed at 120 degree angle intervals.

There are two methods for quantitatively generating rotational axis runout. One is a method of directly oscillating the rotating shaft itself, and another is a method of vibrating the sensors to simulate the pseudo shaft runout. In this experiment, in order to generate quantitative shaft runout, a method of vibrating the sensor unit was used. The three sensors are units and are installed on the XY piezo control stage as shown in Fig.2. The XY piezo control stage can freely generate various vibrations in the X and Y directions in synchronization with the rotation angle of the rotation axis. Also, since each sensor head needs to adjust the posture such as the gap between the sensor head and the gear, it is attached to the 6-axis stage.

3.3. Experiment and Results

In the experiment, the rotating shaft with the gear was rotated at the rotation speed of 5 rpm in the CW direction. Three kinds of experiment setup were carried out for the shaft runout vibration by the piezo stage.

Exp. Setup 1: Shaft runout drawing a one periodic circle with a radius of 5 µm in the CCW direction

Exp. Setup 2: Shaft runout drawing a 15 periodic circle with a radius of 5 µm in the CCW direction

Exp. Setup 3: Shaft runout drawing a square of one circle with one side of 10 µm in the CCW direction

Figure 3 shows the runout value detected by GMRE. The left figure and the right figure in Fig. 3 show the measurement results of experiment setup 1 and setup 2, respectively. Because the number of analysed points is 256 points per 1 shaft turn, the axis runout of setup 2 is drawn at only 17 points per 1 runout turn and looks a little smooth. The dash-dotted line in Fig. 3 indicates a circle with a radius of 5µm ±1 µm. From this, it can be seen that GMRE has detection sensitivity within ±1 µm.

Figure 4 shows experimental results of setup 3. It is understood that the three MR sensors mounted on the piezo stage accurately detect the artificial shaft runout generated in a square shape with a side of 10 µm. The square looks slightly bulging because there is a frequency component of the shaft runout that cannot be detected by SelfA⁺. The experimental system generates virtual shaft runout by vibrating the MR sensors. Therefore, we must also consider that the oscillation detected by the GMRE is added with vibration of 0.03 µm of the air bearing of the rotating shaft with the gear in addition to the vibration generated by the piezo stage.

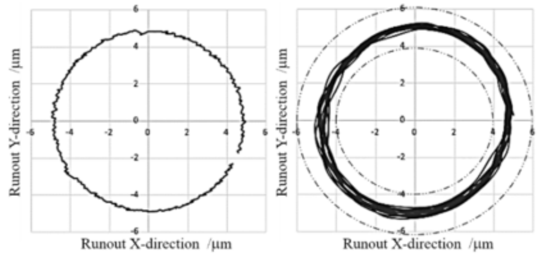

Figure 3. Runout detected by GMRE by SelfA⁺ principle.
Left shows the Exp.setup 1, and Right shows the Exp. Setup 2.

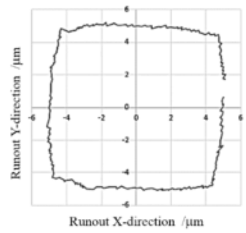

Figure 4. Runout for setup 3 detected by GMRE by SelfA⁺ principle.

4. Conclusion

GMRE using MR sensor was proved to be able to detect shaft axis runout with accuracy of 1 µm or less by using the principle of SelfA⁺. The ability of the GMRE 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.

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