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CALIBRATION OF A POLYGON MIRROR
BY THE ROTARY ENCODER CALIBRATION SYSYTEM

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Abstract – In this paper, we propose the new calibration measurement method of a polygon mirror. The measuring method of the conventional polygon mirror that uses an index table needs much technical skill, much time, and the amount of work. We used the Equal-Division-Averaged (EDA) method [1] and have already developed the self-calibration system that calibrates the angle graduation signal of two sets of rotary encoders simultaneously. By combining this system and a polygon mirror, it becomes possible to measure the angle between faces of a polygon mirror. Now, in Japan, the angle traceability system which used the rotary encoder as the base of angle measurement device is established. If this technology is applied and a polygon mirror can be measured, it will make it easy to build a polygon mirror into the same traceability system.
Keywords: polygon mirror, rotary encoder, angle standard

1. INTRODUCTION

Now, a polygon mirror is measured by a certain method in the angle between face to face, and the value is used as an angle standard by transfer a value to other angle measuring instruments. The position is equivalent to the block gauge in a length standard. It is used for international comparison etc. However, the method which generally used the index table and the autocollimator is adopted as measurement of a polygon mirror. The problem of this method is that the calibrated autocollimator is needed, in order to detect a small angle change from front face of the polygon mirror. The calibration data covering several 10˝ are required at least for the autocollimator.

In this research, we proposes the new measuring method of the polygon mirror which can moreover be measured with high precision at high speed by using a rotary encoder self-calibration system, the calibrated autocollimator is not needed (It is used in order to only find out the front of a polygon mirror.). Now, National Metrology Institute of Japan (NMIJ) studies development of all the circumferential angle graduation calibration technology of a rotary encoder (Fig. 1) [2], and that standardization, and is building the traceability system for angle standard. When polygon mirror measurement by the

rotary encoder self-calibration system is attained, it will become easy for a polygon mirror to be included in angle traceability.
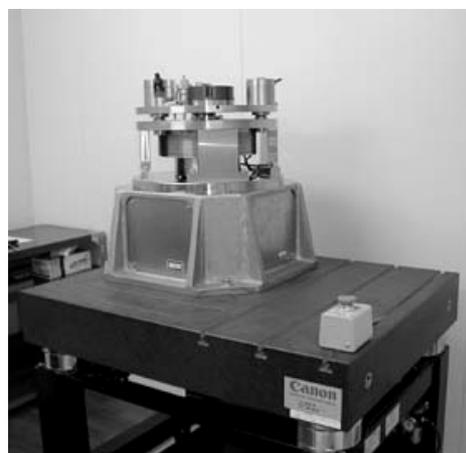

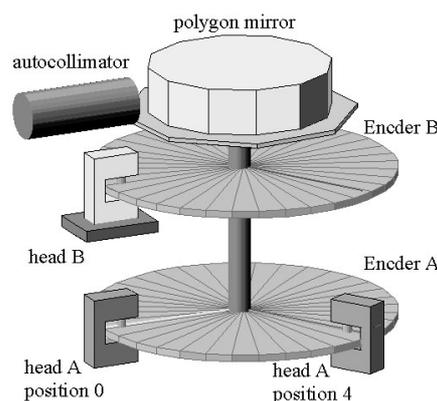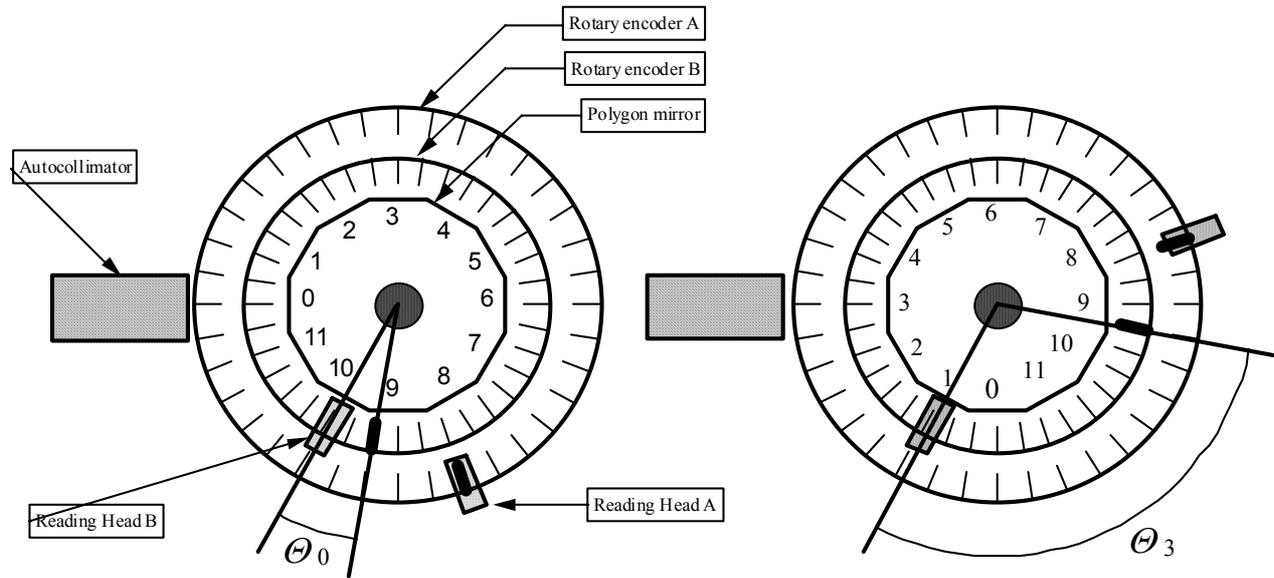Fig. 1. The rotary encoder self-calibration system

Fig. 2. The calibration principle of the polygon mirror
by the rotary encoder self-calibration system

2. EXPERIMENT AND RESULTS

As shown in Fig. 2, the rotary encoder measurement system built in two sets of the rotary encoders A and B. When calibrating a polygon mirror, the polygon mirror and two sets of rotary encoders are installed in the same axis. The reading head B of encoder B and the autocollimator are fixed. However, the reading head of

Fig. 3,1 (Left), Fig. 3.2 (Right)

The calibration principle of the polygon mirror
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Fig. 4 The graduation position relation of
the rotary encoders A and B

Fig. 5 The time dependence of graduation signal

encoder A is controlled and can be fixed to the arbitrary positions of 360 °.

from the encoders A and B.

2.1. Calibration procedure

1) As shown in figure 3.1, the face index 0 of the beginning of a polygon mirror is detected by the autocollimator at the front. At this time, since an autocollimator only detects the front, the calibration does not have to be carried out for the angle of an autocollimator, that is, only the stability of that detection becomes important.

2) Control a reading head A position to the starting point (Fig. 3.1, face index 0). At this time, the reading head B is not necessarily the starting position of the encoder B.

3) Rotating the whole, measure the difference of the angle from the starting point of the encoder B to reading head B. The graduation position relation of the rotary encoders A and B is shown in figure 4, and the time scale of timing that each reading head detects a graduation signal is shown in figure 5. Angular-difference Θ_j is shown by the following equation.
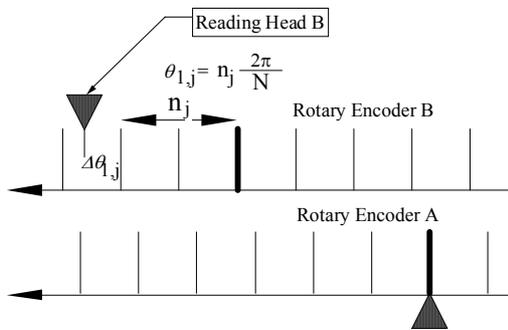
$$\Theta_j = \theta_j + \Delta\theta_{1,j} \qquad (1)$$

$$\theta_j = n_j \frac{2\pi}{N} \qquad (2)$$

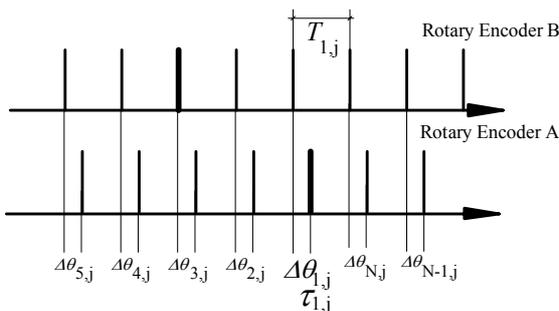$$\Delta\theta_{i,j} = \frac{\tau_{i,j}}{T_{i,j}} \frac{2\pi}{N} \qquad (3)$$

Here, i (i= 1, 2, 3, …N) and j (j= 0, 1, …max face index number of the polygon mirror) of a subscript show the graduation number from the starting point of the encoder A, and the face index number of a polygon mirror, respectively. Here, N is the total number of graduations that the encoder B has. θ_j shows the angle calculated by the number n_j counted the angle graduation signals from the reading head A detects the starting point to the reading head B detected the starting point. Therefore, it is shown

by the equation (2). $\Delta\theta_{i,j}$ shows an angle until the reading head B detects the first graduation signal from the time of the reading head A detecting the starting point. This angle is computable by transforming time using a equation (3), as shown in figure 5. $\tau_{i,j}$ shows gap of the graduation signal of encoder A and B. $T_{i,j}$ shows time which the graduation interval of encoder B takes. Since $\Delta\theta_{1,j}$ of a equation (1) shows the angle that the following graduations with which Encoder A caught the starting point signal, they are set to i= 1. While a rotary encoder rotates, we measure $\Delta\theta_{i,j}$ of the same number as the total graduation numbers, then the measurement accuracy can be more precise by calculating the average of $\Delta\theta_{i,j}$. That is, it is expressed by the following equation.

$$\Theta_j = \theta_j + \sum_{i=1}^{N} \frac{\Delta\theta_{i,j}}{N} \qquad (4)$$

4) Stop rotation and detect the next face (Fig.3.2 shows the face index 3 =90 °) of a polygon mirror to measure by the autocollimator.

5) Control the reading head A to a starting position again (Fig. 3.2, face index 3).

6) Perform the same operation as 3) for measuring the Angular-difference Θ_3

7) Compute the angle of face to face of a polygon mirror from the difference of the data of 3), 6).

2.2. Experiment and results

Figure 1 and 2 show a photograph of the calibration system in the AIST and the schematic set up of the calibration system for a polygon mirror. The system has two reference encoders A and B (laser angle encoder X-1M, 225000P/R manufactured by Canon Inc.) is mounted on a precise air bearing. The speed control range is from 0.1rpm to 10rpm. An uncertainty of rotating speed in the case of 5rpm is 0.01%, and the uniformity in rotation of one graduation of the reference encoder is within 0.1%.
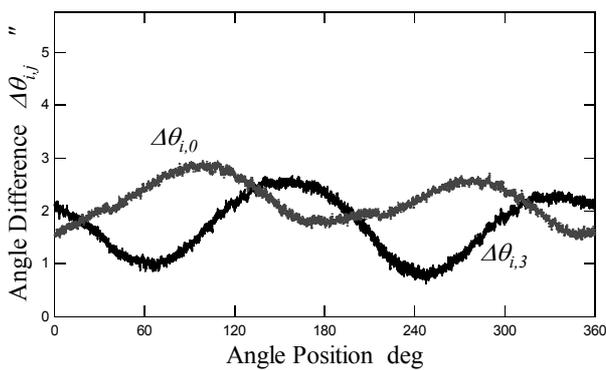

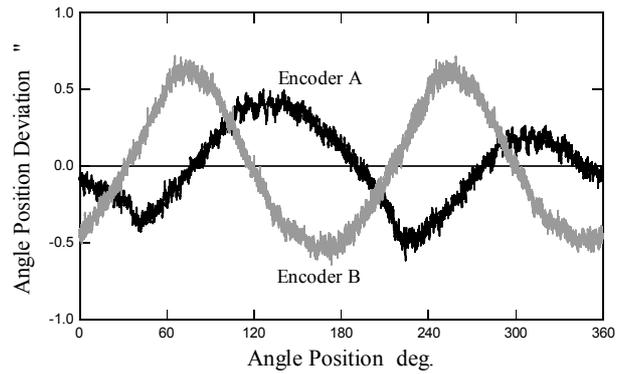Fig. 6. $\Delta\theta_{i,j}$ data at the face index j=0,3

Fig. 7. The calibration curve of the two rotary encoders A and B by EDA method

Fig. 6 shows the two data $\Delta\theta_{i,0}$ and $\Delta\theta_{i,3}$ that are corresponded to the polygon face index j=0 and 3 respectively. Since the total number of graduation line is 225,000, then n_0-n_3 is counted to 56250, so θ_3-θ_0 = 56250 / 225000 * 360 ° =90 °, and the difference of the angle between faces can be evaluated from 90 ° + ($\Delta\theta_{i,3}$-$\Delta\theta_{i,0}$). Both data show the large amplitude of angle difference that the size is about ±1″. The reason is that both rotary encoders still have the graduation position gap and the gap will ride on data. If we use the calibration data of rotary encoder A and B calibrated by using the self-calibration system, then the data reduce the amplitude and become easy to be understand the difference of the value $\Delta\theta_{i,0}$-$\Delta\theta_{i,3}$. Figure 7 shows the calibration result of the two rotary encoders A and B. This self-calibration system can calibrate the graduation of an encoder by the uncertainty of 0.01″ or less now. By performing the correction the gap, obtaining data with still smaller uncertainty is expected.
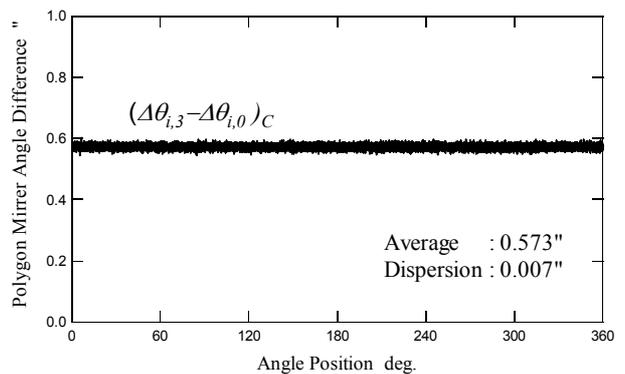

Fig. 8. The calibration curve of the two rotary encoders A and B by EDA method

Figure 8 shows final result of $(\Delta\theta_{i,0}$-$\Delta\theta_{i,3})_C$. Although the standard deviation of the data which Fig. 6 shows is about 0.3 ″, however after the correction, the standard deviation of $(\Delta\theta_{i,0}$-$\Delta\theta_{i,3})_C$ become the very small value to 0.007 ″. This experiment shows the angle between face indexes 0 to 3 is 90°+0.573 ″. The angle between other face indexes can be measured by the same procedure. Although there is also the method of comparing directly the graduation of the encoder

calibrated by the encoder self-calibration system and polygon face, in this case, it is required like the method using an index table that an autocollimator should be calibrated. By this method in comparison with two encoders, in order to measure the small angle, it has measured using time interval as Fig. 5 shows. Therefore, although it tends to think that uniform rotation is required, there is no such thing. The reason is that it has realized local uniform rotation velocity by measuring the ratio of time whenever it measures $\Delta\theta_{i,j}$ as shown in equation 3.

3. CONCLUSIONS

In the angle standard, a polygon mirror is an important measurement object with which international comparison is performed. When measuring the angle accuracy of a product also in a company, there is much spot where the polygon mirror is used. Therefore, development of the technology which calibrates a polygon mirror at high speed and with high precision is a very important subject.

This research shows the implementability of a calibration of the highly precise polygon mirror that used the rotary encoder, and shows that it is possible to include a polygon mirror in the traceability system of the angle standard.

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