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# COMPACT SELF-CALIBRATABLE ROTARY ENCODER

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**Abstract:** SelfA (Self-calibratable Angle device) rotary encoder has an advanced function that can detect and estimate the angular deviation in the signal by itself. National Metrology Institute of Japan (NMIJ) developed the small and low cost SelfA encoder with keeping high accuracy ±0.2″.

**Keywords:** Angle, Encoder, self-calibration.

## 1. INTRODUCTION

A lot of angle encoders are used for industrial equipment for the purpose of the angular measurement and the control. There is no encoder that can evaluate its angle accuracy after it was installed into the device in practical use, therefore both the manufacturer and the user of rotary encoders were in trouble because the accuracy of the angle encoder was unclear in use.

Some rotary encoder calibrations principles and equipment that can calibrate a rotary encoder or self-calibration principles that rotary encoder can calibrate by itself have been introduced as show in table 1[1-5]. Since those systems have some disadvantage such as large system size or long measurement time, it has not come to put in practical use widely. X. D. Lu and D. L. Trumper invented the new self-calibration technique that can calibrate the existing rotary encoder in the state where it attached to the air spindle without other high accuracy calibration tool[6]. This method is one of the methods nearest to utilization now.

SelfA[7-9] is a simple structure only to arrange several sensor heads in surroundings of one scale disc at equiangular degree intervals, it can detect and calibrate the scale error, an attachment eccentricity error and bearing error with high accuracy by only one revolution. This measurement capability of the angle accuracy at any time leads to the quality, reliability, safety and security improvement of the product with built-in SelfA encoder. In this paper we introduce the reduced size and improved capabilities of SelfA encoder.

## 2. PRINCIPLE OF SELFA ENCODER

SelfA encoder has several number of sensor heads which are arranged around one scale disc at same angular interval as shown in Figure 1. One arbitrary sensor head is chosen as a main head $A_1$. While the scale disc is rotating one round revolution, the comparison measurement of the angular signal difference $\delta_{i,(1,j)}$ between the main head $A_1$ and other heads $A_j$ is carried out. Where, $i$ ($i$ = 1, 2, ⋯, $N_G$) represent a graduation line number, $N_G$ is the total graduation number of a scale disc, $j$ ( $j$ = 1, 2, ⋯, $N_H$) is a sensor head number and $N_H$ is the total number of sensor heads.

When the angular deviation of $i$-th graduation position from an ideal graduation position represents $a_i$, and the main sensor head detects the $i$-th position, then the $j$-th head detects the graduation position of the $i+(j-1)N_G/N_H$ at same time. Therefore, the signal difference $\delta_{i,(1,j)}$ is written as follows:

$$\delta_{i,(1,j)} = a_i - a_{i+(j-1)N_G/N_H} \quad . \tag{1}$$

The difference $\delta_{i,(1,j)}$ is calculated against each sensor head j, and mean value $\mu_i$ is calculated. It is expressed with the following formula,

$$\mu_i = \frac{1}{N_H}\sum_{j=1}^{N_H}\delta_{i,(1,j)} = a_i - \frac{1}{N_H}\sum_{j=1}^{N_H}a_{i+(j-1)N_G/N_H} \quad . \tag{2}$$

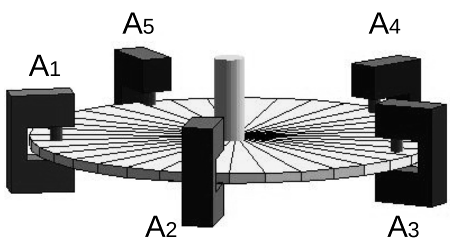


Fig. 1 Set up of self-calibratable rotary encoder. A1 is main head. ($N_H$ = 5 sensor heads).

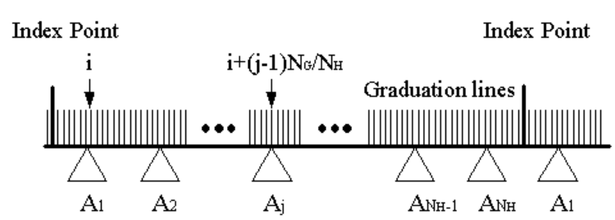


Fig. 2 Position relation between a rotary encoder scale and sensor heads of self-calibratable rotary encoder.

Here, we use the law of the Fourier series written in the following that can be mathematically proved about arbitrary periodic curve,

> "An arbitrary periodic curve of 2π can be expressed by the Fourier series, and when n-number of curves with a phase shift of 2π/n are averaged, the averaged curve shows the sum of an integral multiple of n-order Fourier components of the original curve".

According to this law, the mean value $\mu_i$ represents the calibration curve of rotary encoder, however it does not include $N_H$ -th order Fourier components corresponding to 2nd term of right side in eq.2.

## 3. COMPACT SELFA ENCODER

We have developed the large-sized and highly precise SelfA encoder in order to install in a high accuracy rotating table[8] or angular national standard equipment[9]. In this paper, we developed an affordable price and downsizing SelfA encoder for the purpose of its widely practical application.

Figure 3 shows the sensor heads array circuit board and its graduation scale. The circuit board is installed 6 sensor heads that has 2 array arrangements, one is 120° interval of 3 heads and another is 90° interval of 4 heads such as $N_H$ =3 and 4 Multi Combination SelfA[9] set up. The sensor head is SMD-01 produced by SEIKO NPC CORPORATION. This is a consumer product used as a linear encoder sensor for control of the electromotive zoom lens of a camera. It is a high-precision optical encoder that employs a diffraction image projection method. It incorporates an OEIC (Opto-Electric Integrated Circuit) and LED light source in a single package. Miniature clear-mold package size is ($5.3\times4.3\times1.68$ mm$^3$), and its resolution is 20 μm pitch pattern scale. The sensor heads are pasted up on the circuit board by reflow soldering process that is low cost process.

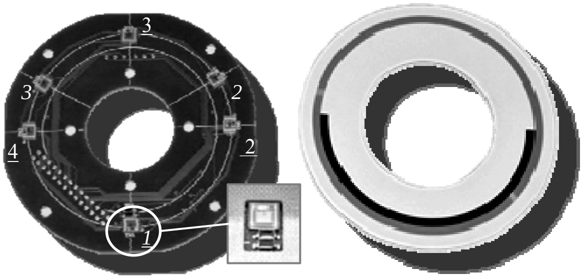

Fig. 3 The sensor heads array circuit board and its graduation scale for SelfA rotary encoder.

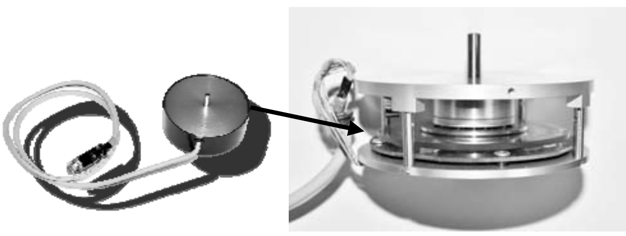

Fig. 4 The SelfA rotary encoder unit which built in the sensor heads circuit board and the scale disc.

Therefore, the sensor head position may be misalignment against the ideally designed layout to the order of hundreds of micro meters to 1 mm.

The rotary scale disc (KOSHIBU PRECISION CO., LTD.) has 10800 graduation lines and its scale pitch is 20 μm and angle interval corresponds 120", so that optical diameter is about 68.75 mm. The graduation scale lines are written by sputter deposition on soda-lime glass.

## 4. EXPERIMENT AND RESULTS

In order to estimate the ability of the angular deviation detection function of this SelfA rotary encoder, it is attached on the primary angular standard[4][5] at NMIJ and compared between the SelfA calibration data and a calibration data is calibrated by the primary standard as a general rotary encoder. Figure 5 show the angular deviation is analyzed by SelfA algorism, big one periodic sinusoidal sine curve is caused by three reasons, one is an eccentricity between scale center and encoder shaft, second is also eccentricity between encoder shaft and shaft of the primary standard and last reason is graduation angular error. The curve of the small amplitude near zero line is the value which removed the one periodic sinusoidal sine by fitting analysis.

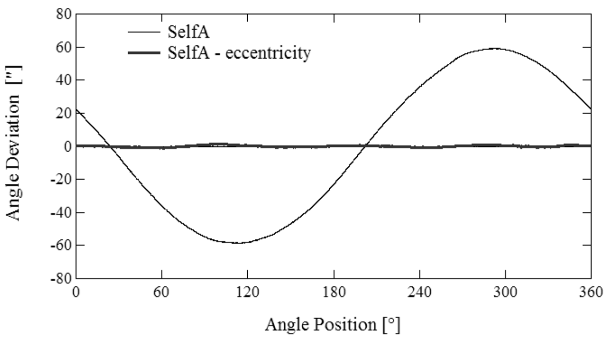


Fig. 5 Calibration result of SelfA rotary encoder.

The Figure 6 shows two of the scale angular deviation data which are removed the influence of one periodic sinusoidal sine error sources from SelfA (as shown in figure 5) and from calibration data by primary standard. Since two data show same value, it turns out that the compact SelfA maintaines highly angular deviation detection capability.

In order to evaluate this performance more in detail, the differential value of two data is shown in Figure 7. Furthermore, the result in frequency analysis of the differential value using the Fourier transform is shown in Figure 8. This difference value is very small and is about ±0.2″. By correction of the signal outputted from this SelfA rotary encoder using the angular deviation shown in Fig. 5, even if it does not use high accurate calibration equipment, it is possible to make SelfA encoder highly precise by itself.

SelfA of $N_H$ =3 and $N_H$ =4 cannot detect 3n-th and 4n-th frequency components of the angular deviation, therefore, $N_H$ =3 and 4 Multi Combination SelfA cannot detect 12n-th frequency components[9]. As for the fact that the frequency component of the multiple of 12 is also dominant of the frequency analysis in shown in Fig. 8, the experiment result shows that this principle can be realized correctly.

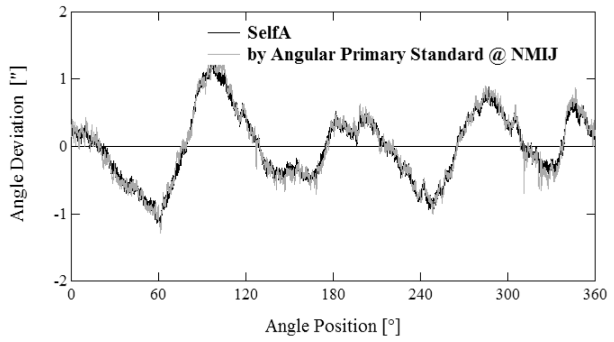


Fig. 6 The scale angular deviation analysis by SelfA and the angular primary standard at NMIJ.

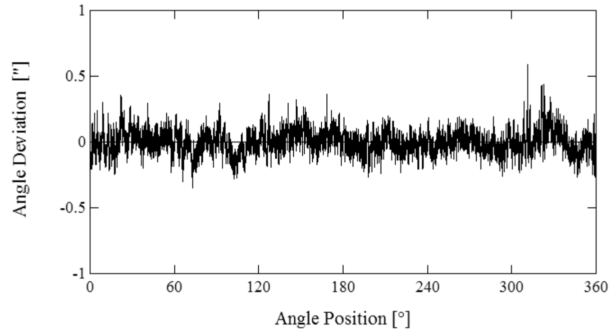


Fig. 7 The differential value of two data is shown in Figure 5.

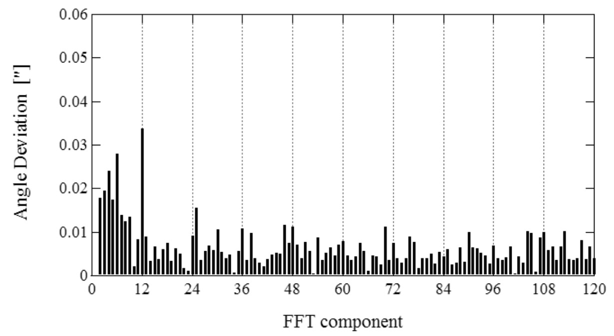


Fig. 8 The frequency analysis result of the data is shown in Figure 6.

## 5. CONCLUSION

We developed a compact and low cost SelfA rotary encoder. The manufacture expense of this SelfA encoder body is about 1,500 USD (exclude the cost of the data acquisition board), and anyone is able to manufacture this simply. In the experiment, the angular deviation including the factor of eccentricity error of about ±60" has been detected with high accuracy at about ±0.2" by comparison with an angular national standard equipment. Since there is still sufficient space between the sensor and sensor which are arranged on a circuit board as shown in Fig. 2, this compact SelfA encoder can be miniaturized further.

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