Development of Optical Absolute Sensor "ABS-EC" Having High Accuracy and High Resolution

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1. Introduction

The sensors used in servo motors can be classified into two types: incremental sensor and absolute sensor, and ever-finer sensors are being developed in many fields.

Especially in the automobile industry, there is a trend to changing materials, from conventional casting to lightweight aluminum in order to decrease fuel consumption and preserve the environment. Thus accurate processing is required for small machine tools.

Sanyo Denki's "ABS-E" optical absolute sensor has been widely used in such machine tools. We have developed a new "ABS-EC" with the following two element technologies based on the proven technologies of the "ABS-E":

(1) Development and utilization of eccentricity correction technology (self-alignment)

(2) Development of high-resolution encoder signal

We think this "ABS-EC" meets needs of not only machine tool market also FA market in general, where servo unit is common.

This is a description on the theory and implementation of the high accuracy and resolution of "ABS-EC".

2. Outline of Eccentricity Correction Technology (Self-Alignment)

2.1 Relation between Amount of Eccentricity and Amount of Jitter

When a rotary disc has eccentricity as shown below, the detected angle of the detected points A and B changes, resulting in jitter that appears in the encoder characteristics.(Fig. 1)

An example of the calculation is shown in Table 1.

(1) Amount of change of detected angle

$= \arctan \{ L / (R - r) \} - \arctan \{ L / (R + r) \}$

(2) Jitter = Amount of change of detected angle/angle per pitch $\times$100 (%)

2.2 Relation between Amount of Jitter and Absolute Error

High accuracy can be obtained by subtracting the value of error α as shown in Fig. 2.

2.3 Relation between Eccentricity and Absolute Error in an Actual System

The absolute angular error of detected point 1 can be expressed by the linear equation:

$(\psi + \theta sa) - (\psi + \theta - 6°) = \theta sa - \theta + 6°$

$= \arctan \{ r \times \sin (\theta - 6°) / RA \}$ ···(1)

The absolute angular error of detected point 2 can be expressed by the linear equation.

$$(\psi + \theta sb) - (\psi + \theta) = \theta sb - \theta$$
$$= \arctan \{ r \times \sin\theta / RB \} \cdots (2)$$

Angle between detected points 1 and 2:

$$\theta sb\,(\theta) - \theta sa\,(\theta) = \{\theta + \alpha b\,(\theta)\,)\,\} - \{ \theta + \alpha a\,(\theta) - 6^\circ \}$$
$$= \arctan (r \times \sin\theta / RB) - \arctan \{ r \times \sin(\theta - 6^\circ) / RA \}$$
$$+ 6^\circ \cdots (3)$$

Therefore, the angular error of detection between detected points 1 and 2 can be expressed by the following equation:

$$\beta(\theta) = \theta sb\,(\theta) - \theta sa\,(\theta) - 6^\circ$$
$$= \arctan (r\times \sin\theta / RB) - \arctan \{ r \times \sin(\theta - 6^\circ) / RA \} \cdots (4)$$

From Fig. 3 the maximum angular error of detection on the positive side occurs when $\theta = 3^\circ$:
$\beta\ (3^\circ) = \arctan (r \times \sin 3^\circ / RB) - \arctan \{ r \times \sin(-3^\circ) / RA \}$
The maximum angular error of detection on the negative side occurs when:
$\beta\ (183^\circ) = \arctan (r \times \sin 183^\circ / RB) - \arctan \{ r \times \sin(177^\circ) / RA\}$
Therefore, the amount of eccentricity can be detected by measuring the maximum value and the minimum value (jitter) of the angular error of detection (phase difference) between the detected points 1 and 2.
At the same time, when the amount of eccentricity is detected, the correction value for the absolute angular error can be calculated from equation (1).
Fig. 4 shows an example of evaluation data of actual absolute angular error.

2.4 Summary of Eccentricity Correction Technology

To manufacture a high accuracy encoder, the eccentricity of rotary disc must be required. However, detection accuracy of encoder is much sensitive for centering accuracy in disk and hub assembling and coupling accuracy of shaft into hub. It has been difficult to manufacture efficiently and certainly a high accuracy encoder by conventional way.
The new technology solves this problem, and achieves the development target.

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3. Method of Achieving High-resolution Encoder Signal

3.1 Problem of Conventional Method

High-resolution encoder signals can be obtained by using optical processing by narrowing the slit width of the rotary disc and stationary mask. However, simply narrowing the slit width is limited due to the diffraction of light. As a result, it has been difficult to manufacture a high-resolution encoder.

3.2 Outline of Solution

(1) When the PD output is amplified by a differential amplifier, a quasi-sine waveform similar to a triangular wave is obtained. The position of the present value when located in the range of one pitch, can be known by measuring the voltage of a quasi-sine wave.
(2) Sine waves having 90° electric phase angle between each other can be generated

by amplifying the sine waves using two pairs, i.e., four elements of PD. A high-resolution encoder signal can be generated by measuring the cross-point value of the sine waves and by voltage-dividing the linear portion of the sine wave that has high linearity.

3.3 Circuit Block Flow

Fig. 5 shows the circuit flow of generating the original signal data to generate a high-resolution signal.

3.4 Outline of Signal Switching Signal and Measured Voltage

Fig. 6 shows the ideal signal waveform after amplification by the differential amplifier. The A/D converter input signals are switched by the comparator output. The portion of the signal that is shown by the thick line in Fig. 5 is A/D converted. Values of Va, Vb, Va*, and Vb* that are shown in Fig. 6 are measured.

3.5 Method of Achieving High Resolution

When the measured voltage of the A/D converter is Vx,comparator outputs of A and B* are HIGH, and comparator outputs of A and B are LOW,the value X after dividing into high resolution can be expressed as follows:
X = [(Va - Vx) / 2 { Va - Vb*) + (Va*) - Vb }] × [number of divisions]
and 2 { Va - (Vb*) + (Va*) - Vb } > [number of divisions] is also required.

Therefore, the accuracy of division is limited by the number of bits of the A/D converter circuit, but up to 256 divisions can be realized by increasing the number of bits of the A/D converter circuit.

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4. Outline Block Diagram of High-accuracy, High-resolution ABS-EC

Fig. 7 shows the theory and method of high accuracy and high resolution.

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5. Conclusion

We have described briefly the theory and method of achieving high accuracy and high resolution for the "ABS-EC". The core of the sensor detector element (rotary disc module and light receptor module) has been standardized for various products, and so can be used for a wide range of products from top-end models to economy models. Conventional sensors can be replaced with the new sensor by exchanging the circuit board module.

Furthermore, the sensor can be installed without adjustment by using the newly developed vibration-proof connector and fixing jig.

"ABS-EC" is suitable for new applications and fields in addition to conventional applications.

We are working to improve the accuracy, reduce cost by stable analog signal, increase the data transmission speed and investigate and develop more intelligent ASICs for low-cost, highly reliable products.

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(Example of calculating amount of eccentricity and amount of jitter)

Table 1

Eccentricity (mm)	Jitter (%)
0	0
0.001	1.9
0.002	3.9
0.003	5.8
0.004	7.7
0.005	9.6
0.006	11.6
0.007	13.5
0.008	15.4
0.009	17.4
0.01	19.3
0.011	21.2
0.012	23.1

R = 4.5
L = 1.5
Basic number of divisions
= 8192 slits/rotation
Angle per pitch
=360/8192 = 0.044 degrees

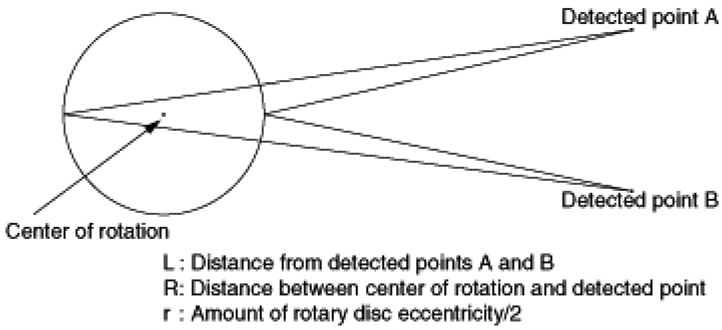
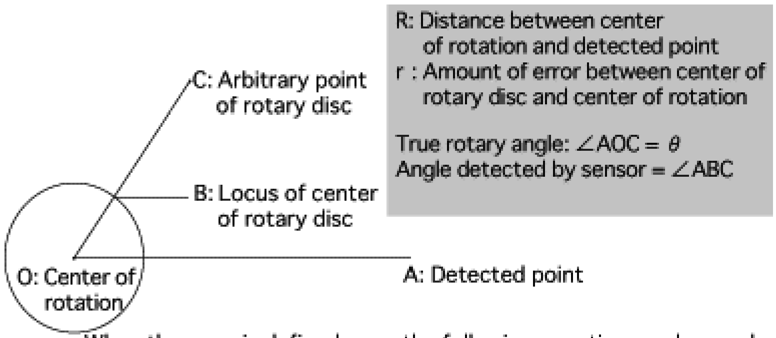


Fig. 1 Relation between amount of eccentricity and amount of jitter



When the error is defined as α , the following equation can be used:

$\alpha = \angle AOC - \angle ABC = \angle OAB = \arctan\{r \times \sin\theta / (R-r) \times \cos\theta\}$

When $R \gg r$

$\alpha = \arctan\{r \times \sin(\theta) / R\}$

Fig. 2 Relation between jitter and absolute error

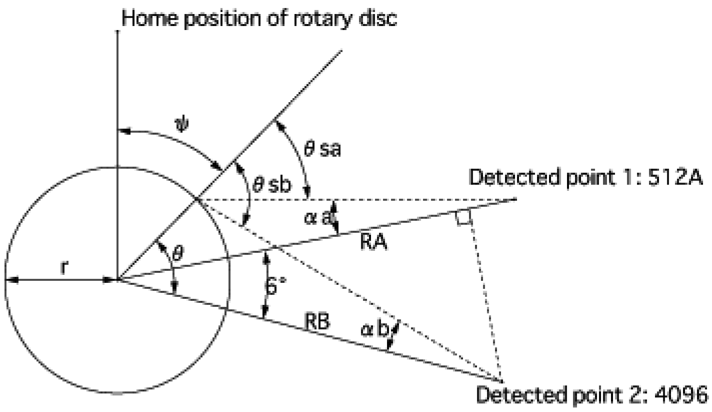


Fig. 3 Relation between eccentricity and absolute error

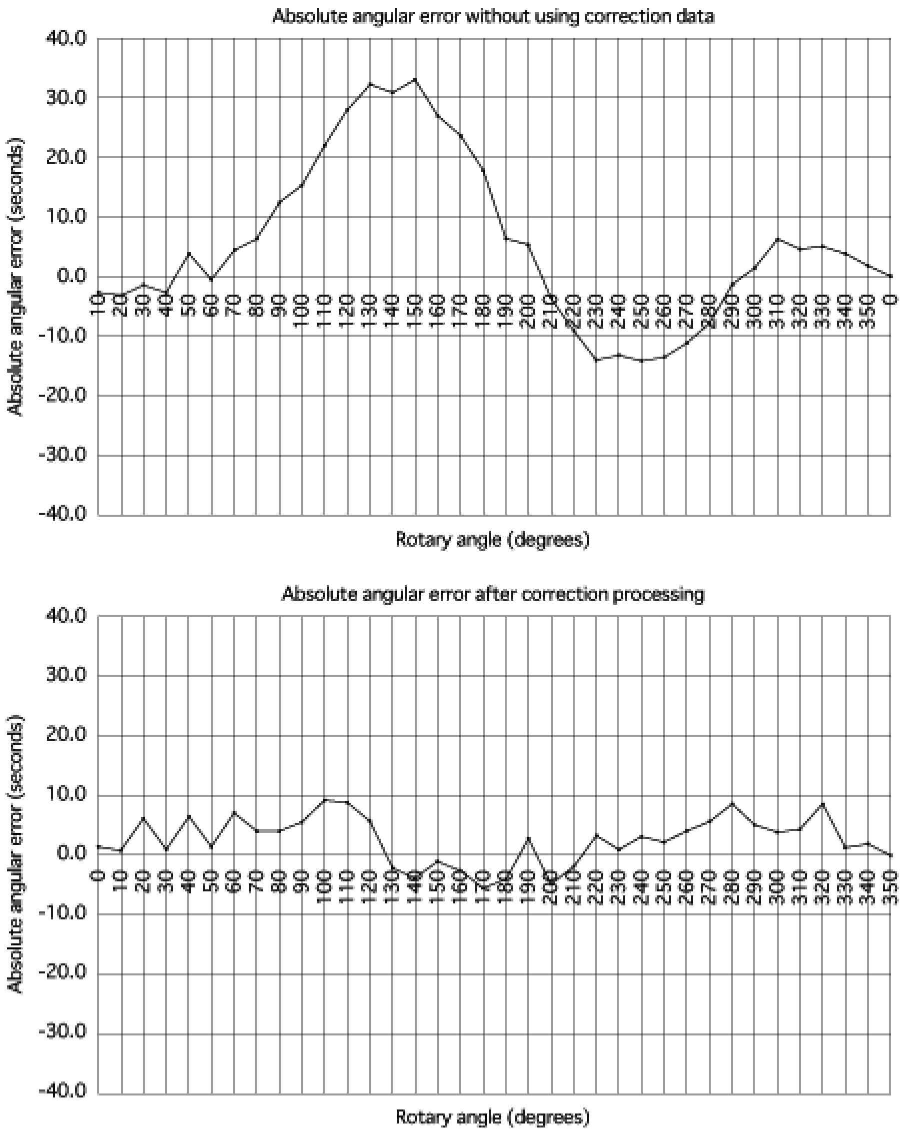


Fig. 4 Example of evaluation data of an actual machine

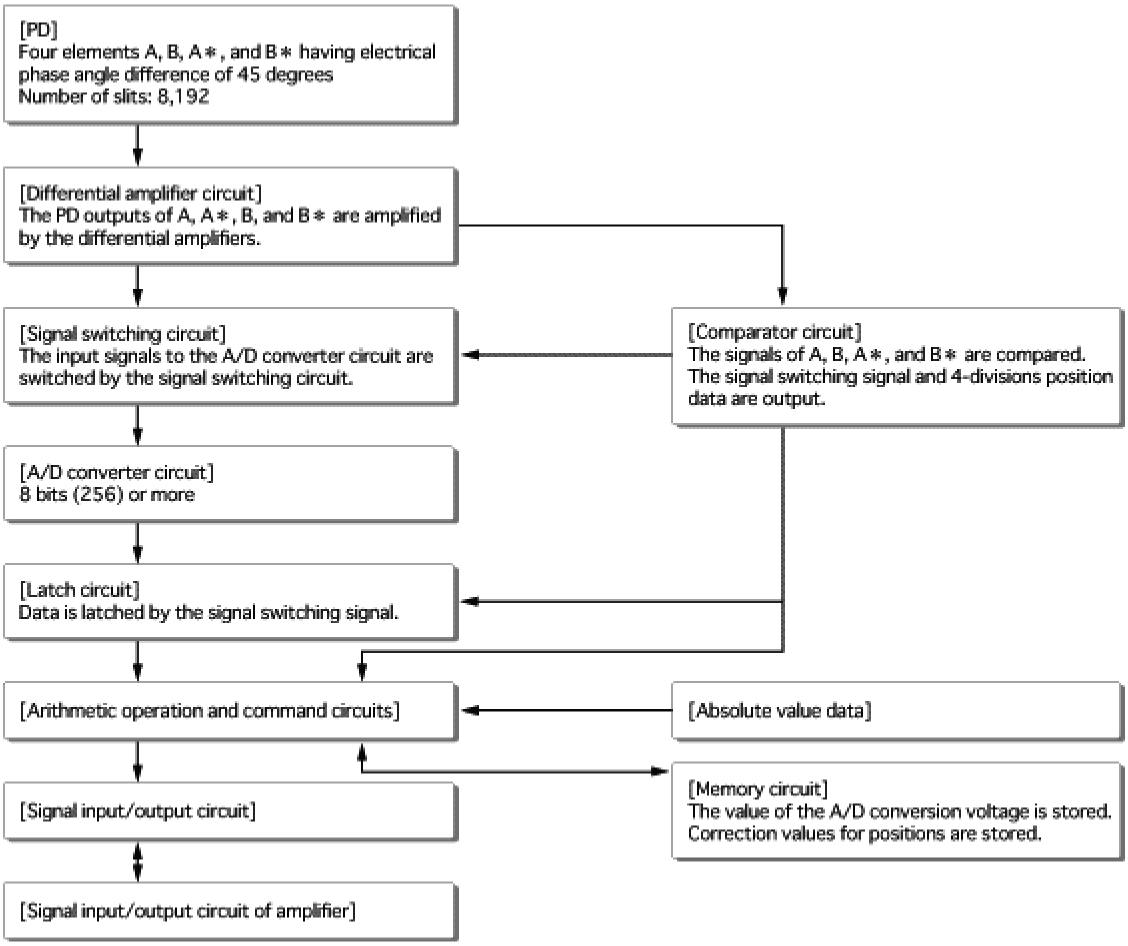


Fig. 5 Circuit Block Flow

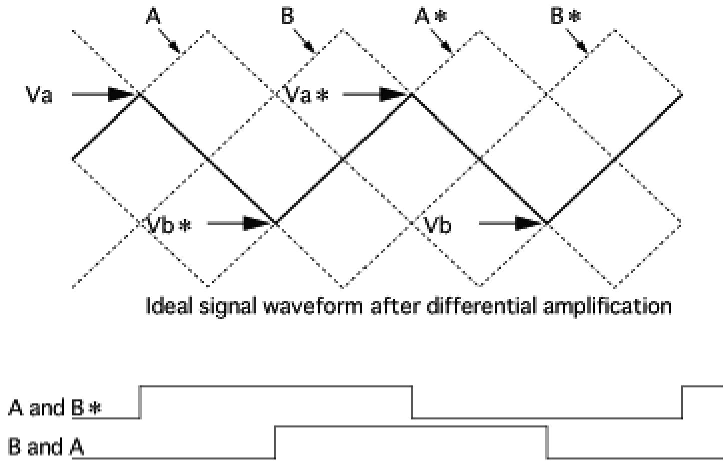


Fig. 6 Output waveform of comparator circuit

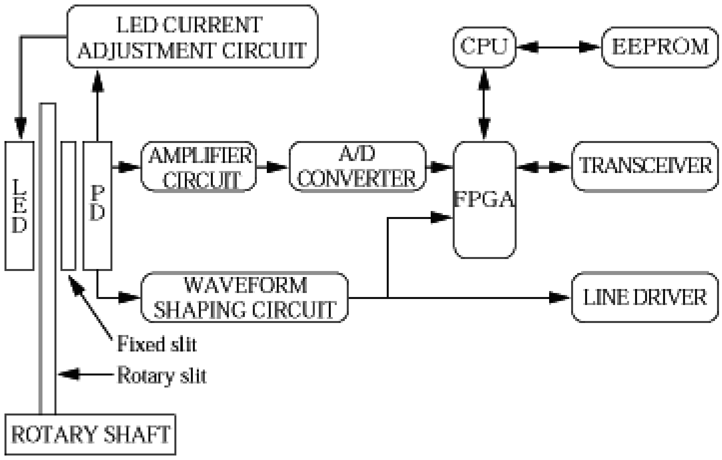


Fig. 7 Outline block diagram of high-accuracy, high-resolution ABS-EC