

# Recent Encoder Technology

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## 1. Introduction

The encoder, a type of angle detection sensor, has greatly advanced with the trend toward higher performance servo systems.

This trend is driven by demand for drastically improved resolution, and 16-bit (corresponding to 16,384 pulses) encoders are now appearing in the market instead of encoders with 2,048 pulses, which had been the standard up to the present.

Such being the background, special features of the recent encoder are as follows.

- (1) Realization of small and high resolution encoder
- (2) Standard provision of absolute function
- (3) Economy of cables by adopting serial transmission
- (4) Provision of intelligent function

## 2. Improvement of Optical Encoder Performance

### 2.1 Improvement of resolution

There are two methods, mechanical and electrical (interpolation), to realize a drastic improvement in encoder resolution.

The mechanical method improves resolution of the encoder by increasing the number of the slits of the revolving slit disk. For this purpose, the width of a slit must be as small as possible, requiring high precision machining and assembling of the element parts.

Recently there are several electrical methods to achieve high resolution, one of which is to realize high

resolution by electrically interpolating the approximate quasi-sinusoidal wave shaped A and B signals from the photo detectors, as shown in Fig. 1.

### 2.2 High accuracy

This section explains technical matters related to the realization of high accuracy in the method shown in Fig. 1. This method is required to reduce distortion of the 2 quasi-sinusoidal waves shape as small as possible in order to improve the position accuracy.

For this purpose, it is necessary to analyze and optimize LED (light emitting diode), the slit disk, the characteristics of the photo detector and the effect of the relative positioning of such components that compose the detective part.

It is possible to analyze the effect of such parameters on the distortion of 2-phase signals by a simulator as shown in Fig. 2. This simulator photographs, with a CCD camera, the intensity distribution of light that passes through the slit disk, and then calculates the photoelectric current generated by each photo detector from this image data.

Figure 3 shows the result of analysis of the change of 2-phase signal outputs where the distance between the slit disk and the photo detector is a parameter. It is possible from this analysis, showing the distortion factor and the amplitude, to design the most appropriate distance between the slit disk and the photo

Fig.1 Example of achieving high resolution

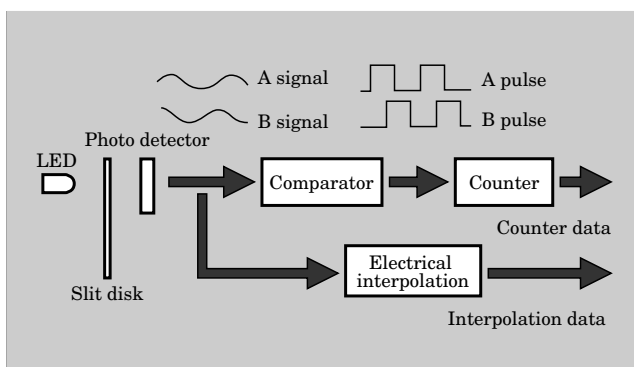


Fig.2 Simulator for analyzing optical system

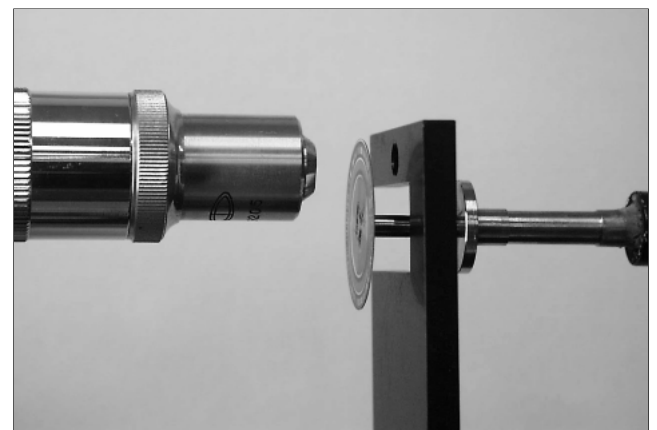


Fig.3 Simulation results

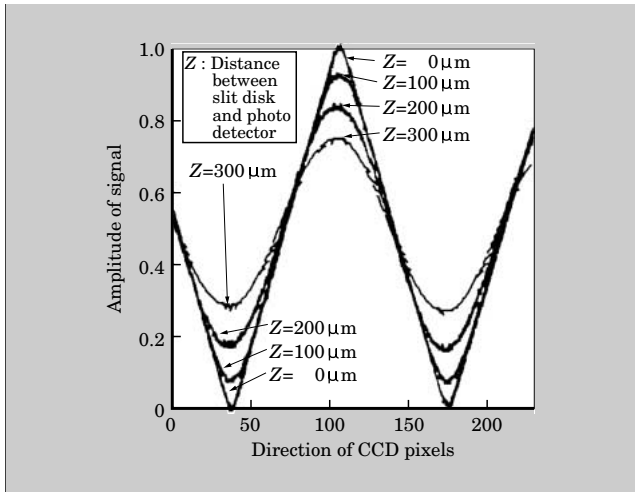
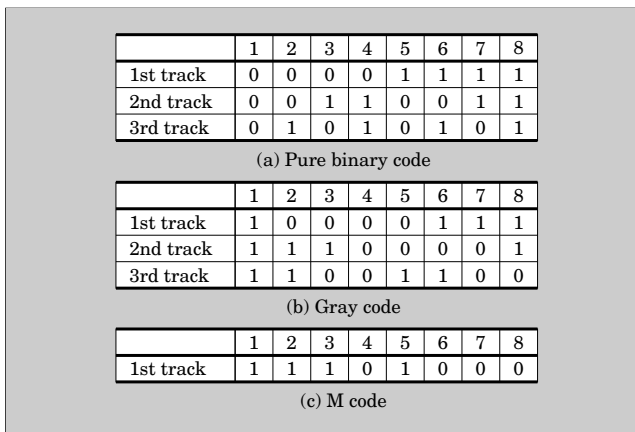


Fig.4 Code pattern (3 bits)



detector.

### 2.3 Absolute encoder

The absolute encoders were only utilized in a limited range of applications because of their handling difficulty and high cost due to their complicated construction. Recently, absolute encoders, which do not require an origin return operation, have become necessary for applications where origin return operation is difficult, such as in a multiple robot or unmanned factory. In order to realize the absolute encoder it is necessary to provide a position detection (to absolutely detect a position in one revolution) and a revolution number detecting function (to detect the number of revolutions). The position detection must continue operation even if the servo-amplifier does not receive electricity, in which case the batteries installed outside of the encoder shall supply electricity to the encoder. For this reason, it is required that the position detection part consumes low electric energy, and recent encoders are provided with a permanent magnet to detect the revolution number magnetically.

Generally, the typical performance is indicated by the resolution of the position detecting function.

Fig.5 Configuration of gray code system and data conversion

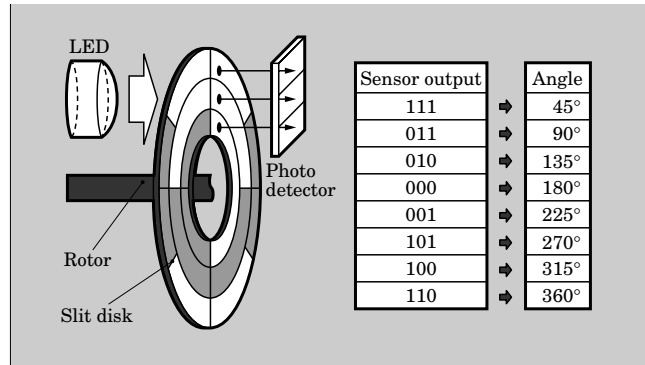
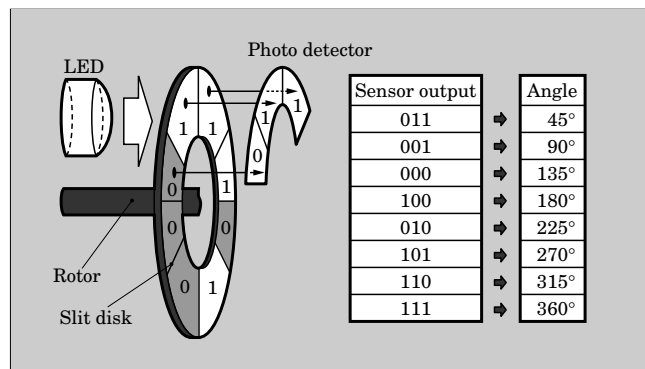


Fig.6 Configuration of M code system and data conversion



Therefore, the algorithm to detect the absolute position by the position detecting function affects the overall composition and performance of the encoder. There are two methods used in recent encoders to detect the absolute position.

#### (1) Gray code system

Figure 4 shows various code patterns of the absolute encoder. Gray code is different from the pure binary code shown in Fig. 4 (a), and more than two (inclusive) codes do not change at the same time as shown in Fig. 4 (b).

Three slit disks, each provided with a grating consisting of permeation portions corresponding to "1" and covering portion corresponding to "0", are arranged concentrically, and three photo detectors, facing the disks, are arranged in a row in the radial direction as shown in Fig. 5. The disadvantage of this method is that it is difficult to reduce the radius.

#### (2) M code system

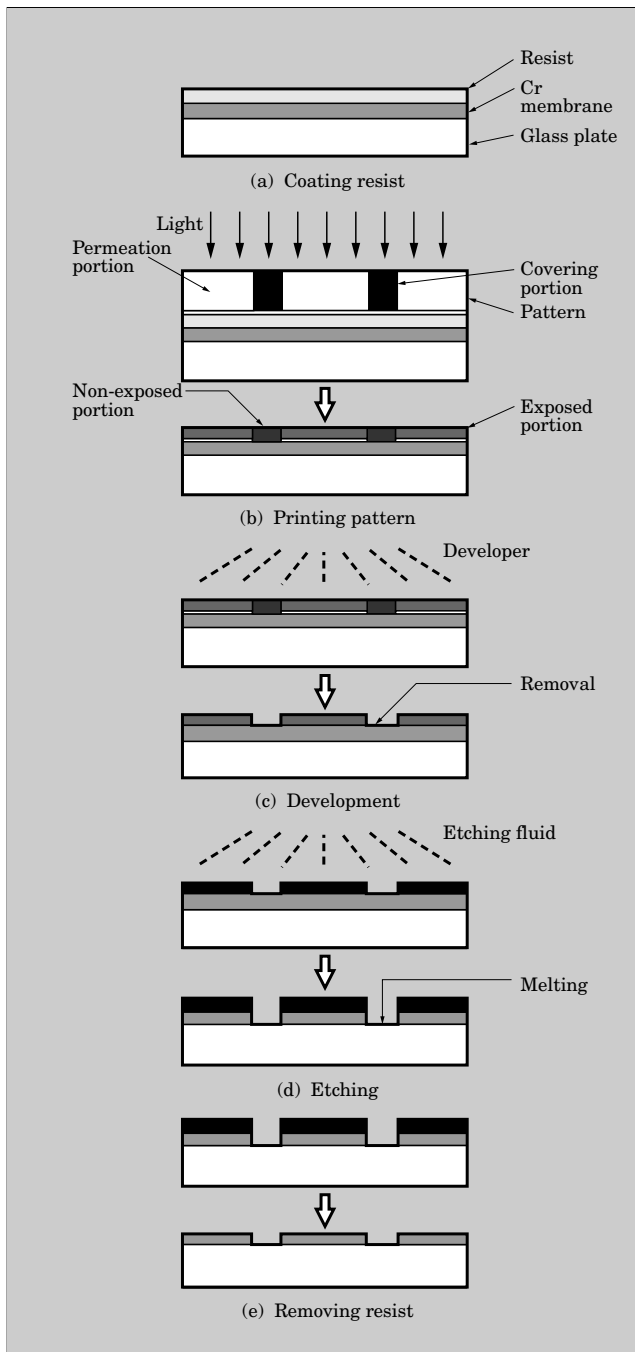
M code is a random number code constructed from a simple rule and consists of  $2^n$  combinations of "1" and "0" data per one cycle as shown in Fig. 4 (c).

Since there is only a single piece of data, given by a series of 1s and 0s from any particular position, there exist  $2^n$  unique data values, along the periphery.

Figure 6 shows the encoder with an M code slit disk.

In this case, it is easy to achieve a small radius, since the photo detectors are arranged along the circumference.

Fig.7 Photoetching process



### 3. Element Technology of Optical Encoder

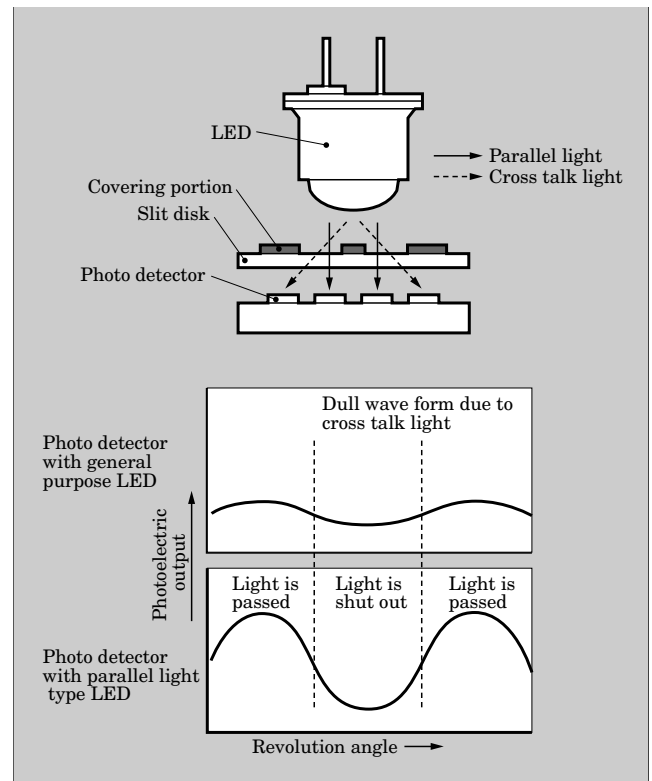
#### 3.1 Photo detector

The photo detector is a transducer that converts a light signal, passing through the slit disk, into an electrical signal, and typically consists of a photo diode and phototransistor.

The photodiode is constructed such that light is applied to its p-n junction, and its main features are quick response, linear light-current characteristics, low noise, etc.

The phototransistors are a combination of a photo-

Fig.8 Effect of cross talk



diodes and a transistors for amplification integrated into a single unit. Its advantage is that it can generate a large signal, equal to the photoelectric current of the photo diode multiplied by the amplification factor of the transistor. Its disadvantages include slow response and different light-photoelectric characteristics depending on each phototransistor.

To compensate for these disadvantages, recent encoders use semiconductor wafers, on which a photodiode and a phototransistor are mounted, so that an appropriate encoder may be used corresponding to the specifications of the light signal.

#### 3.2 Slit disk

The hot etching method is generally used to manufacture the slit pattern, and the manufacturing process for a glass slit disk differs from that for a metal slit disk.

The pattern of the glass slit disks is manufactured in the following process as shown in Fig. 7: (a) coat the Cr sputtered glass surface with the resist membrane, (b) print the pattern, (c) develop, (d) etch, and (e) remove the resist membrane. A glass slit disk made by this method has advantages of excellent etching accuracy and high resolution, as well as disadvantages of vibration and shock susceptibility and high cost.

In the case of a metal slit disk, the metal slit disks are directly etched and therefore the etching accuracy is not as high as that of the glass slit disk and is not suitable for high resolution. However, it does have advantages of high resistance to vibrations and shocks

Table 1 Serial transmission codes (electrical/mechanical specifications)

System Evaluation item	RS-232C	RS-423	RS-422	RS-485
Transmission speed	To 20 kbps	To 300 kbps	To 10 Mbps	To 10 Mbps
Transmission distance	To 15 m	To 600 m	To 1,220 m	To 1,220 m
Transmission operation	Unbalanced	Unbalanced	Balanced	Balanced
Maximum connection	1 driver/ 1 receiver	1 driver/ 10 receiver	1 driver/ 10 receiver	32 driver/ 32 receiver

and low cost. Recently the film slit disks have been developed to improve the disadvantageous of both types mentioned above.

### 3.3 LED

LEDs for the encoder are provided by the various manufactures. When selecting LEDs, the following points shall be considered.

#### 3.3.1 Parallel light characteristics

The cross communication (talk) light component will lower the signal-to-noise ratio as shown in Fig. 8 and reduce the detection accuracy.

Hence, an LED that emits a wide range of parallel light is preferable.

#### 3.3.2 Light intensity vs. temperature characteristics

The light intensity of an LED per unit of forward current is lowered by temperature rise. For this reason, it is necessary to flow a larger forward current at high temperature than at normal temperature in order for the photo detector to output a constant photoelectric current.

The increase of the forward current of the LED shortens the life of the LED exponentially. Therefore, LEDs, for which the light intensity reduction due to temperature rise is small, are utilized to realize longer life of the encoder.

#### 3.3.3 Uniformity of illumination

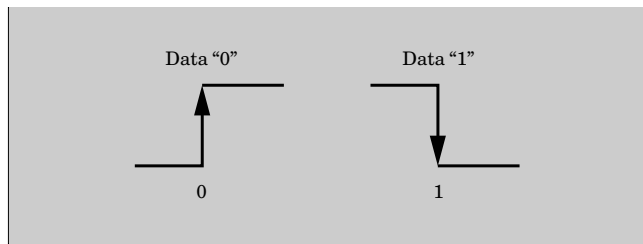
The photoelectric current of the photo detector varies if the uniformity of illumination is uneven. Especially in the case of the encoder, which achieves high resolution by electrically interpolating the sinusoidal wave shaped output signal from the photo detector, the distortion of A and B signals prevents accuracy from improving. For this reason, LEDs with highly uniform illumination are utilized.

### 3.4 Construction

Encoders are classified as ① shaft type, ② hollow shaft type, ③ modular type, etc., according to their method for mounting on motors and method for securing the revolving part. Each type has a different construction.

Of these types, the hollow shaft type is becoming dominant due to such reasons as encoder miniaturiza-

Fig.9 Manchester code



tion and ease of replacement.

The hollow shaft type encoder is provided with a shaft whose center is hollow. The motor shaft can be inserted into the hollow shaft of the encoder to achieve a shorter length in the shaft direction than that of shaft type. In addition, it is easier to mount and replace the hollow shaft type encoder than modular type encoders.

On the other hand, it is necessary to pay special attention to heat and shock resistance characteristics, since all parts of the encoder are susceptible to heat and shock directly transmitted from the motor.

## 4. Encoder and Servo-Amplifier Communication, Intelligent Function

### 4.1 Communication between encoder and servo-amplifier

Regarding the communication between the encoder and the servo-amplifier (herein after referred to as "encoder communication"), the customary pulse transmission system to transmit A · B · Z signals in parallel cannot meet the requirement of high resolution, since the transmission frequency is limited. On the other hand, the resolution is not limited fundamentally by the transmission frequency and the cable between the encoder and the servo-amplifier can be minimized to transmit the position data in serial.

In the case of serial transmission, absolute position data is transmit in real-time, resulting in drastically improved reliability of the transmission line for correctness of the position, compared with the pulse transmission system. Therefore, it is general trend of recent high resolution encoders to adopt a serial transmission system between the encoder and the servo-amplifier.

### 4.2 Serial transmission system

High speed transmission of several megabits/second is required as the communication cycle of the encoder largely affects the response characteristics of the servo system. Because the length of the transmission line can reach 100m at maximum, it is necessary to pay special attention to the voltage drop and noise along the transmission line.

Standard mechanical and electrical specifications for serial transmission are shown in Table 1. RS-422 and RS-485 can be said to be suitable for encoder communication from the viewpoints of transmission

Fig.10 Serial communication block diagram

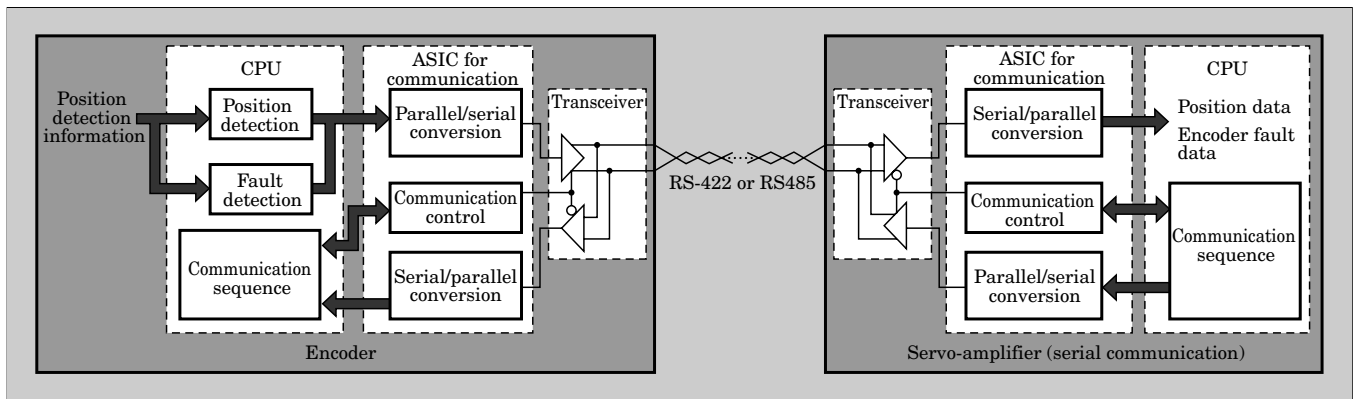


Table 2 Self-diagnosis

Function	Summary
Motor type and output	Informs servo-amplifier of motor type (verifies whether it matches servo-amplifier type)
Abnormal communication	Detects a disconnection of transmission line, CRC (cyclic redundancy checks) error, etc. at the servo-amplifier
Overheat	Informs the servo-amplifier of higher temperature than the setting value in the encoder
Abnormal number of pulse	Informs the servo-amplifier when the number of pulses per one revolution differs from the design number

speed, transmission distance and adoption of a balanced transmission system with noise resistant characteristics. Manchester code is usually applied for its excellent transmission efficiency and high transmission speed. This code is a two value code, and indicates an upward edge as “0” and a downward edge as “1” as shown in Fig. 9.

In addition to the ordinary position signal, cyclic redundancy check data is transmit also to improve the reliability of transmission.

#### 4.3 Configuration of encoder communication system (an example)

To implement a serial transmission system it is necessary to process a huge number of digital signals to convert the position detecting data received in parallel from the optical system. In order to achieve such complicated processing with small number of components in a small space, CPUs (central processing units) and ASICs (application specific ICs) are utilized.

Figure 10 shows a block diagram of the serial communication system, including the servo-amplifier. The CPU of the encoder detects the position as well as faults from various signals detected by optical sensors and other sensors, and carries out the sequential

processing of the communication from the servo-amplifier. An ASIC for communication converts the data of the CPU and that of the transceiver from parallel to serial format and controls communication to the servo-amplifier based on the sequential demand of communication from the CPU. The transceiver converts the input/output signals to RS-422 or RS485 signal levels. It is also necessary to provide the servo-amplifier with a system that includes a transceiver, ASIC for communication and CPU to respond to the encoder’s system. The servo-amplifier receives position data and fault data from the encoder, and controls the operation sequence of the whole system.

#### 4.4 Intelligent encoder

By mounting a CPU and ASIC on an encoder, it is possible to provide an encoder with multiple functions. Hence, the encoder and servo-amplifier are provided with a self-diagnosis function as the position detector, which communicates RAS (reliability, availability and serviceability) information to the servo-amplifier, enabling the servo-amplifier to control the servomotor quickly and safely. Table 2 shows an example of self-diagnosis functions. These functions improve dramatically the RAS function of the position detector.

#### 5. Conclusion

This paper describes encoder technology corresponding to a high performance servo-system applied to various manufacturing equipment, including machine tools, semiconductor manufacturing equipment and industrial robots. Because it is anticipated that demand for higher resolution will continue, Fuji Electric will apply the latest optoelectronics technology and micro-technology for photo detectors and slit patterns to develop a low cost and high reliable encoder as well as achieve higher resolution.



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