多回転バッテリレスアブソリュートエンコーダ「MAR-M700MFA」の開発

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Development of a Multi-Turn Battery-Free Absolute Encoder「MAR-M700MFA」

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アブソリュートエンコーダは，自動車製造ラインの産業用ロボットや工作機械など，産業機械に幅広く利用され，ロボットアーム等の回転変位を絶対値で検出することができるセンサである．2023年11月にリリースした多回転アブソリュートエンコーダ「MAR-M700MFA」は，世界で初めて全固体電池を搭載し，保証温度の向上及びメンテナンスフリー化を実現した．新たに予知保全機能や角度精度自己補正機能を搭載し，産業用ロボット等の利用環境拡大，稼働安定性向上，モーション制御の高精度化に貢献する．本稿では，「MAR-M700MFA」が持つ技術的特徴について解説する．

An absolute encoder is a type of sensor device commonly used in industrial robots in automobile manufacturing lines, machine tools, and various other applications. It detects absolute values for robot-arm rotational displacement and similar measurements. MAR-M700MFA, a multi-turn absolute encoder released in November 2023, offers an increased guaranteed operational temperature range compared to the previous multi-turn external battery-free absolute encoder of the company. This is because of the utilization of an all-solid-state battery, which renders this model maintenance-free. Furthermore, this model is equipped with new features including predictive maintenance and angular accuracy self-correction functions, which enable an expanded range of possible usage environments for industrial robots, improved operational consistency, and greater precision in motion control. This article explains the technical features of “MAR-M700MFA”.

Key words アブソリュートエンコーダ，バッテリレス，メンテナンスフリー，予知保全，角度精度自己補正，全固体電池
absolute encoder, battery-free, maintenance-free, predictive maintenance, angular accuracy self-correction, all-solid-state battery

1 Introduction

An absolute encoder is a sensor widely used in various industrial machines, such as industrial robots in automobile manufacturing lines and machine tools, and it is capable of detecting the absolute rotational displacement of components such as robot arms. In response to diversification of requirements in recent years, functionality of sensors has advanced, and the “MAR-M700MFA” (Fig. 1) is the first in the world to incorporate an all-solid-state battery, thereby achieving an increased guaranteed temperature range and maintenance-free operation. Furthermore, it is equipped with newly developed functions for predictive maintenance and angular accuracy self-correction functions, contributing to an expanded range of operating environments for industrial robots, improved operational stability, and enhanced precision in motion control [1]. In this paper, the technical features of the “MAR-M700MFA” are described.

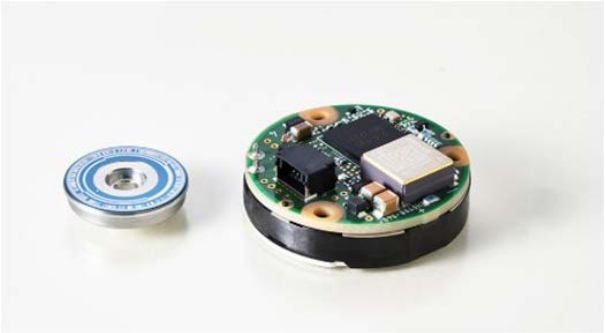

Fig. 1　Multi-turn absolute encoder “MAR-M700MFA”

2 Configuration

Encoder detection methods generally include optical, magnetic, and electromagnetic induction types, and the optical type is often adopted for absolute encoders that require high accuracy and high resolution. The principle of the optical

encoder (Fig. 2) is briefly explained below. When positional displacement (shaft rotation) occurs in an optical encoder, variations in light and dark are generated in the light transmitted through the rotating disk. This variation in light is captured by a photodetector, which is subjected to photoelectric conversion and amplification, and then processed through interpolation (subdivision reading), after which it is output to the host device as positional data [2].

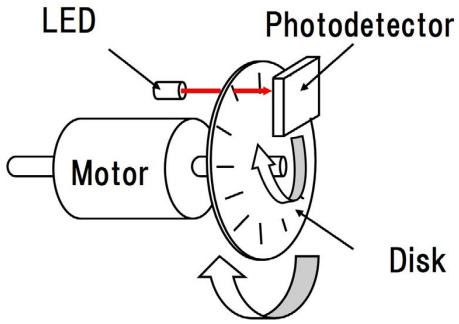

Fig. 2 Principle of the encoder

In recent years, from the perspectives of robot miniaturization and design flexibility, smaller and thinner absolute encoders have been required. A comparison between the conventional transmissive optical system and reflective optical system is shown in Fig. 3.

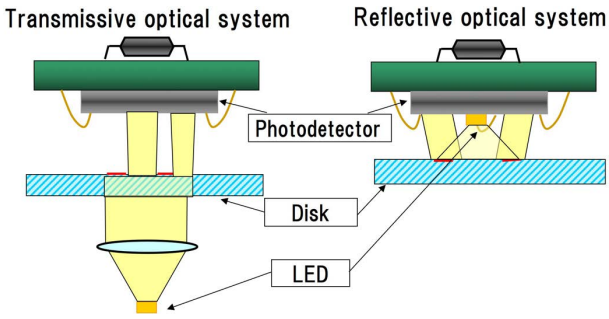

Fig. 3 Comparison of transmissive optical system and reflective optical system

In the reflective optical system, the light source LED and photodetector are arranged on the same plane. In the conventional transmissive optical system, a distance was required between the LED and photodetector, whereas in the reflective optical system, the optical path lengths for projection and reception are shorter, enabling a more compact design. By adopting the reflective optical system, the product height is approximately halved, thereby achieving a lower profile [2], [3]. In addition, while conventional disks were generally made of glass, the reflective type employs a metal disk, thereby improving reliability. In recent years, reflective optical system absolute encoders have become the mainstream, and our company has been employing the reflective optical system for more than ten years. This has enabled us to build a substantial track record and provide an extensive product lineup.

The product introduced here inherits the reflective optical system and has been further evolved with additional functions. In the conventional configuration, position detection was performed with a single optical system, whereas in this product, the optical system is configured with two systems (Fig. 4).

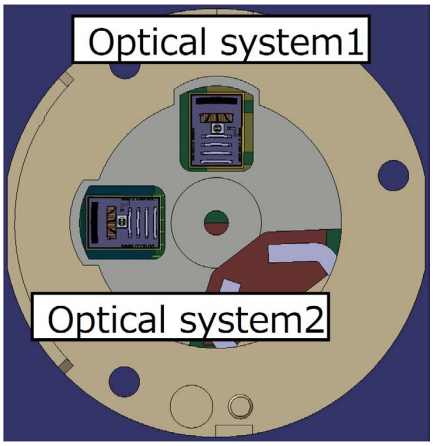

Fig. 4 Arrangement of the two optical systems

By performing position detection with these two independent optical systems, the product is able to provide two sets of positional data. This has made it possible to add predictive maintenance and angular accuracy self-correction functions.

The predictive maintenance function can detect signs of failure in advance and notify the host equipment of the timing for component replacement or maintenance of industrial robots beforehand via the communication protocol (A-format®). As a result, it becomes possible to suppress the risk of sudden stoppages of equipment or production lines due to failures. In addition, the angular accuracy self-correction function enables accuracy correction without the use of a reference encoder, contributing to improved operational stability and enhanced motion accuracy.

Furthermore, in an absolute encoder, in addition to angular absolute position detection, a multi-turn detection function is essential to count the number of rotations. This multi-turn detection function must operate even when the main power supply is turned off; however, in conventional products, an external battery had to be provided on the host equipment side, and the function operated on the external battery power when the main power was off. Therefore, replacement of the external battery is indispensable during maintenance. Moreover, because absolute encoders are combined with AC servo motors, they are often used in high-

temperature environments, making high-temperature tolerance essential for the encoder.

To address these issues, this product incorporates a highly safe all-solid-state battery capable of operating in high-temperature environments, thereby extending the operating temperature range up to 105°C. In addition, by employing a switching element so that power from the all-solid-state battery is supplied to the multi-turn detection unit only when positional displacement occurs, more than ten years of backup is ensured at the time of shipment. Further, depending on the operating temperature, more than ten additional years of backup may be achieved even after ten years of continuous use, thereby realizing long service life. The main specifications are listed in Table 1 [4].

Table 1　Specifications List

External diameter	Φ35 mm
Height	12.48 mm (TYP)
Single-turn Resolution	Max 27 bit
Multi-turn signal Resolution	16 bit
Responsive revolution speed	8,000 min^{-1}
Power source voltage	5 V ± 10%
Current used	120 mA (TYP)
Operating temperature range	−20～+105°C
Communication protocol	A-format®

The product height is 12.48 mm, achieving the same height as that of conventional products. In addition, because it has been designed with compatibility with conventional products in mind, it can be mounted on the motor side without requiring any design modifications.

Next, the details of each function are described.

3 Predictive Maintenance Function

Conventional encoders were equipped only with a function that outputs an error when an abnormality occurs, forcing the equipment to shut down suddenly at the moment the error occurs. A sudden stoppages of a production line not only causes deterioration in product quality and delays in production schedules but also requires time for equipment restart, significantly affecting the overall productivity of the factory.

In contrast, this product incorporates a predictive maintenance function that detects signal degradation in advance and notifies the host equipment. When a degradation in signal quality caused by factors such as LED deterioration is detected, a predictive maintenance alarm is output to the host equipment via A-format®. With this predictive maintenance function, planned maintenance can be carried out before equipment shutdown, making it possible to significantly reduce the risk of sudden stoppages in production lines. Through planned maintenance, component replacement can be carried out at the optimal timing in accordance with the production schedule, thereby minimizing downtime. In addition, because replacement parts can be arranged and maintenance personnel secured in advance, efficiency in maintenance operations can also be achieved. The predictive maintenance alarm is output without affecting equipment operation, making it possible to conduct these preparations while maintaining productivity.

Furthermore, to achieve even higher reliability, the product also provides measures to address random failures. In a product, due to slight variations during manufacturing or potential latent defects, there is a low probability that unexpected failures may occur during its service life. Such random failures are difficult to detect through pre-shipment inspections, and even with countermeasures such as aging, complete prevention is challenging and requires significant cost and time. Even such random failures can be detected at an early stage by means of the predictive maintenance function. However, in the case of random failures, the period from the occurrence of a predictive maintenance alarm to the actual failure tends to be shorter than that for ordinary degradation. Therefore, in this product, the switching function employing two independent optical systems—one for position detection and the other for signal quality monitoring—is used to provide a solution. In the event that a predictive maintenance alarm is triggered in one optical system due to a random failure, the system automatically switches to the other optical system, which is still less affected by degradation and maintains reliability (Fig. 5). This makes it possible to detect and notify signs of random failures in advance while continuing operation in a highly reliable state until maintenance can be performed. In this way, the combination of the predictive maintenance function and dual optical systems ensures stable operation of the equipment.

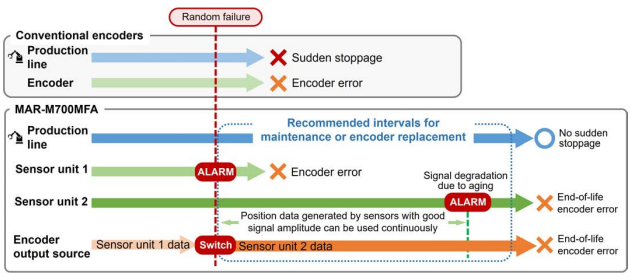

Fig. 5　Image of the switching function

4 A-format®

A-format® is a proprietary communication format for encoders developed by our company. It can output fundamental encoder information, such as position data and temperature data from the temperature sensor built into the encoder, to the host equipment.

In developing this product, the following three functions were added:

- Output of predictive maintenance alarms and status information from each optical system
- Output of velocity information computed within the encoder
- Expansion of the non-volatile memory area for user data

(Output of predictive maintenance alarms and status information from each optical system)

The aforementioned predictive maintenance alarms and status information of each of the two independent optical systems are realized by utilizing previously unused areas, without modifying the data frame structure. As a result, it was possible to add functions while maintaining consistency with the basic specifications and minimizing the impact on the system.

(Output of velocity information computed within the encoder)

Regarding the output of velocity information computed within the encoder, conventionally, it was necessary for the host equipment to calculate the velocity from position data at each communication cycle. In this product, however, velocity is computed internally within the encoder, enabling measurement at shorter intervals and providing more accurate velocity information. The combination of this position data and high-precision velocity data contributes to realizing smoother motion control.

(Expansion of the non-volatile memory area for user data)

Regarding the expansion of the non-volatile memory area for user data, it was previously possible to store information such as the device serial number, operating parameters, and motor-side parameters. With the increased capacity, however, it has become possible to retain a larger amount of information, including various correction data and maintenance records.

In this way, by extending the communication format while maintaining compatibility with the conventional specifications, the product achieves both the addition of new functions—such as the implementation of predictive maintenance function, improved control performance, and expanded storage capacity—and compatibility with existing systems.

5 Angular Accuracy Self-Correction Function

One type of error present in an encoder is repeatable error once per revolution. These errors typically arise from the following factors:

- Errors in the disk pattern caused by manufacturing
- Eccentricity during encoder disk installation
- Runout or angular misalignment of the motor shaft

Errors caused by these factors present a challenge in motor control using encoders, as they lead to issues such as rotational speed fluctuations in the motor itself and, as a consequence, abnormal noise and vibration throughout the entire robot system.

Approaches taken by encoder manufacturers to address errors generally include eliminating fundamental errors through adjustments known as eccentricity correction—aligning the rotational center with the disk pattern center—and improving component precision to the micrometer order. In addition to these, electrical correction within the encoder is also employed.

Several corresponding methods of electrical correction are publicly known, with the representative ones listed below [5]:

- Correction by comparative measurement with a high-precision reference encoder
- Correction by comparative measurement with a reference instrument using the equal divided average method
- Self-correction by incorporating the equal-division averaging method into the product itself

Although many other correction methods exist, conventional electrical correction has faced the following challenges:

- Investment in expensive reference instruments
- Increased working time due to correction procedures
- Enlargement of the product due to self-error detection and self-correction mechanisms

This product incorporates a new correction function that addresses these challenges. Through a proprietary process utilizing dual optical systems, the challenges inherent in conventional methods have been resolved.

In this product, the correction process is executed simultaneously with automatic signal adjustment (Auto Tuning) during product integration. Conventionally, correction work required several minutes, but it has been shortened to less than 15 seconds. The experimental results obtained with a prototype are shown in Fig. 6.

Although it is a relatively small-diameter encoder, which is

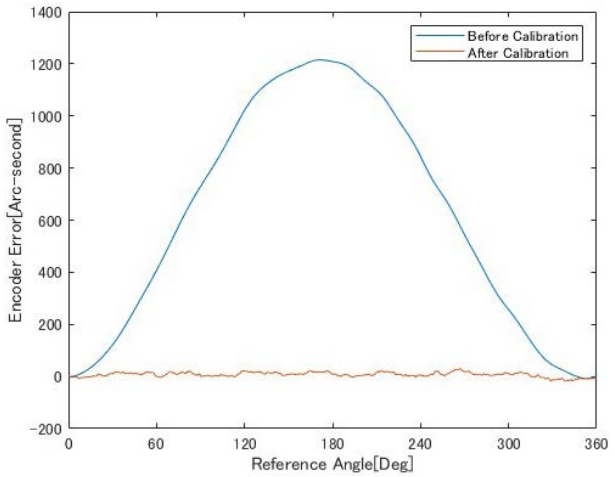

Fig. 6 Accuracy measurement results: comparison before and after correction

known to have larger errors compared to large-diameter encoders, this product achieved a After-self-correction accuracy of 39 counts full width (≈0.0136°) in terms of 20-bit representation, thereby attaining a high-level balance between workability and accuracy. This product is expected to provide new benefits through improved accuracy by means of the angular accuracy self-correction function, not only for users who have long required high accuracy but also for those who previously did not place emphasis on accuracy.

6 Multi-Turn Detection using an All-Solid-State Battery

This product adopts the proprietary multi-turn detection method established in previous models. The built-in battery mounted on the encoder board has been changed from a lithium primary battery to an all-solid-state battery. Because the all-solid-state battery is a secondary battery, a dedicated charging circuit was designed to ensure sufficient backup retention time in actual operating environments—that is, the duration during which multi-turn position information can be retained by the battery mounted on the board when the encoder's main power supply is turned off. Charging of the all-solid-state battery is automatically controlled internally when the encoder's main power supply is turned on. Therefore, in actual operating environments, users do not need to be concerned with charging or discharging, and from the user's perspective, the encoder can be treated as battery-free.

In addition, by adopting the proprietary multi-turn detection method established in previous models, the product inherits the reliability of multi-turn detection and mounting compatibility from previous models, with an equivalent product height. In conventional technologies for battery-free encoders, the mainstream approaches have been either mounting a power generation element on the circuit board and using its output signal for both power supply and position detection, or the gear-based method, both of which result in an increased product height. By employing a proprietary detection method and configuring a magnetic circuit, our battery-free encoder is able to retain a thin, easily mountable mechanism that also includes the method of attaching the encoder disk.

A key feature of the multi-turn detection method of this product is that the output of the power generation element is not used for power supply or position detection but solely for switching to perform multi-turn position detection and its retention (Fig. 7).

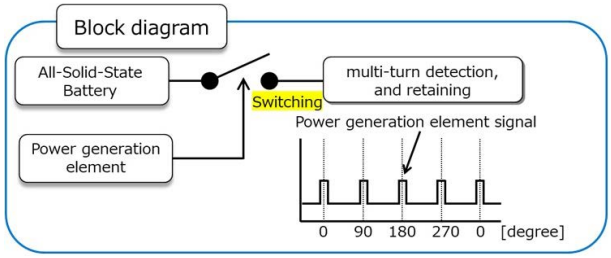

Fig. 7 Block diagram of the multi-turn detection method

When the motor shaft rotates while the encoder is not supplied with its main power, an output signal from the power generation element is generated in the magnetic circuit. As a result, the switching shown in Fig. 7 changes from OFF to ON, power is supplied from the all-solid-state battery, multi-turn position detection and its retention are performed, and once the process is completed, the switching changes back from ON to OFF. Multi-turn position detection in the state where the switching is ON adopts a configuration that momentarily activates the optical detection circuit to read the encoder disk pattern. This detection method is a configuration that combines two different detection systems: a magnetic system that operates the power generation element to switch the circuit and an optical system that actually detects the position of the encoder disk. As a result, even if the encoder is subjected to an external magnetic field in its actual operating environment while the motor shaft is at rest and an unintended power generation element signal is produced, it does not affect the multi-turn position detection, thereby providing an advantage in terms of resistance to external magnetic field disturbances. This has been translated according to the original source text. However, please check if a more suitable alternative would be "the multi-turn

position detection remains robust to external magnetic field disturbances."

7 Conclusion

"MAR-M700MFA" is an absolute encoder widely used in industrial robots and machine tools, incorporating the latest technologies such as precise position detection and enhanced environmental resistance.

This product, while inheriting conventional technologies, significantly enhances performance and reliability compared to previous models through the addition of new functions. As a result, it not only meets the diverse needs of industrial machinery but also achieves greater design flexibility for miniaturization and modularization, as well as stable operation even in high-temperature environments. With its introduction, the product is expected to improve production efficiency (*e.g.*, shortening operating time of manufacturing lines) and reduce maintenance costs (e.g., lowering the frequency of component replacement), and it is also expected to contribute to the advancement of next-generation industrial machinery (e.g., realization of automation and smart factories).

In the future, we will expand the product lineup equipped with these functions and advance the development of products that meet a wider range of applications and diverse needs.

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