Commentary

Development of Multi Track Magnetic Encoder Integrated Rolling Bearing

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The robot industry has been expanding on the back of market demand for improved productivity and labor saving as the countermeasures of diminishing working population. Especially, the demand of small robots such as collaborative robots that work with human labors and service robots has been increasing. Through the recent trend, market requirements for the robots have been getting higher and more diversified.

NTN has developed the "Multi Track Magnetic Encoder Integrated Rolling Bearing" based on the technology of the "Multi Track Magnetic Ring" for rotary encoders. The bearing is suitable for robot joints and performs high-precision angle detection as well as the shaft support. This report introduces the features, structure, and performance of the bearing.

1. Introduction

The use of robots to perform work instead of humans is on the increase throughout the world in all industrial manufacturing sectors, including for automobile manufacture[1) 2)]. In recent years we have experienced significant social problems such as the decline in the working-age population ratio due to the decreasing birthrate and aging population as well as slow production activity due to the increase in COVID-19 infections, prompting the increased introduction of robots. Industrial robots installed in production lines, robots that work in locations away from humans, and small robots such as collaborative robots and service robots are on the increase, while the structure of robots and the work they do has become increasingly diverse.

Vertical articulated robots **(Fig. 1)** that move similar to the arms of a human are typical, and such robots must transport a workpiece with high accuracy and speed to a determined position. To achieve this, the joint mechanism must be able to support the motor's rotating shaft while detecting its rotational speed, rotational direction, and absolute angle with a high level of accuracy to achieve the correct position. In addition to servo motors and reducers, robots use bearings to support rotation and rotary encoders to detect rotational conditions[3)].

Furthermore, recent joint mechanisms must support the diverse trends as mentioned above, and to be compact, lightweight, be assembled from as fewer parts as possible to reduce man-hours to build them and have a high environmental resistance so they can be used in various operating conditions.

So far **NTN** has commercialized the highly accurate and compact Multi Track Magnetic Ring for use in detecting the absolute angle and rotational speed for the robot joint mechanisms[4)]. The Multi Track Magnetic Ring, in combination with the magnetic sensor IC, forms a magnetic rotary encoder that provides high environmental resistance.

The application of this technology contributes to greater improved performance for robot joint mechanisms, so **NTN** has developed a new "Multi Track Magnetic Encoder Integrated Rolling Bearing" (hereafter, developed product) that brings together the bearing, the Multi Track Magnetic Ring, and magnetic sensor IC in a single unit. The developed product supports the rotation of the shaft while detecting the rotational speed, rotational direction and absolute angle as a rotary encoder. Bringing together the bearing and magnetic rotary encoder in a single unit can make the robot joint mechanism more compact and reduce the man-hours required for assembly and setup in the robot manufacturing process. The developed product's features, structure and test results are introduced below.

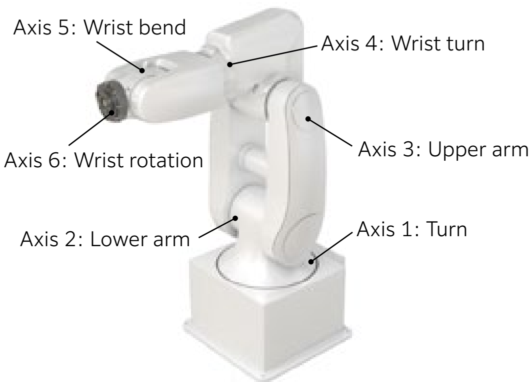

Fig. 1 6 axes vertical articulated robot

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2. Developed product structure and features

The developed product is a unit composed of a deep groove ball bearing, Multi Track Magnetic Ring, and magnetic sensor IC **(Fig. 2)**.

The Multi Track Magnetic Ring is attached to the inner ring of the deep groove ball bearing. The magnetic sensor IC is attached to the outer ring of the deep groove ball bearing through the sensor housing. The developed product can be used for joint mechanisms on the robot as shown in **Fig. 3**. The Multi Track Magnetic Ring rotates as the axis rotates, and to correspond to the rotation the magnetic sensor IC reads the change in magnetic poles. This enables the developed product to detect the rotational speed, rotational direction, and absolute angle. Data detected by the magnetic sensor IC is transmitted to a motor driver prepared by the user, then used for positioning the robot joint mechanisms **(Fig. 4)**.

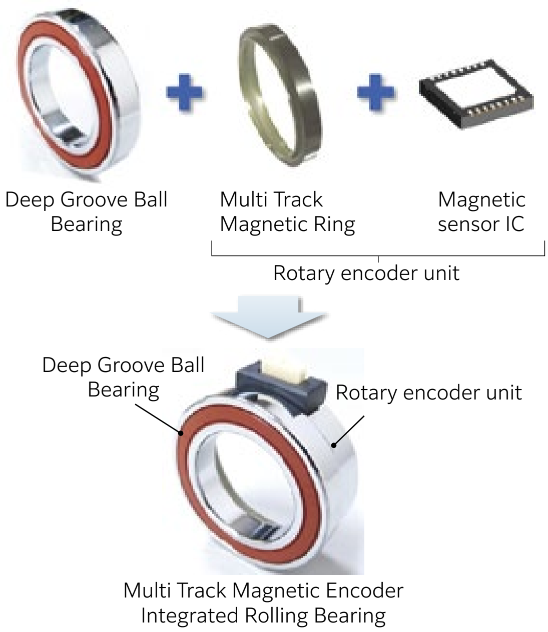


Fig. 2 Configuration of major components for the Multi Track Magnetic Encoder Integrated Rolling Bearing

Fig. 3 Positions where the Multi Track Magnetic Encoder Integrated Rolling Bearing can be used

The developed product is a compact unit that uses technology to integrate the rotation detection unit and bearing that **NTN** has developed for conventional rotation sensor bearings **(Fig. 5)**, which are well-established for use in transportation machinery[5]. It has the same bearing bore diameter, outer diameter, width, and load rating as a standard bearing without the rotation detection unit, making it compatible with standard bearings. This unit's features are shown in (1) to (4) below. **Table 1** also shows the specifications for the developed product using deep groove ball bearing 6907.

(1) Can support shaft rotation and provide high accuracy angle detection.

The developed product detects rotational speed, rotational direction, and absolute angle while supporting shaft rotation. Configuring parameters in the magnetic sensor IC enables a maximum high accuracy output of 20 bits (resolution of approximately 0.00034°).

(2) Contributes towards making the robot joint mechanism compact and lightweight.

Integrating the deep groove ball bearing, Multi Track Magnetic Ring and magnetic sensor IC means that a coupling to connect the joint mechanism and rotary encoder is not needed. This enables a reduction in the joint mechanism shaft length, the use of fewer components, and results in producing a more compact and lighter joint mechanism **(Fig. 6)**.

(3) Can reduce man-hours for robot assembly and setup.

As mentioned above in (2), integrating components can reduce the number of robot components, which reduces man-hours required for assembly. It also means that the user does not have to perform setup such as adjusting output signals required for when assembling the magnetic ring and magnetic sensor, so man-hours can be reduced.

(4) Affected less by the surrounding environment and high environmental resistance.

The developed product is a magnetic rotary encoder that detects the rotational speed, rotational direction and absolute angle using magnetism. In comparison with optical rotary encoders that use light for detection, it is affected less by the surrounding environment such as temperature changes, dust, and oil, and has a high environmental resistance[6].

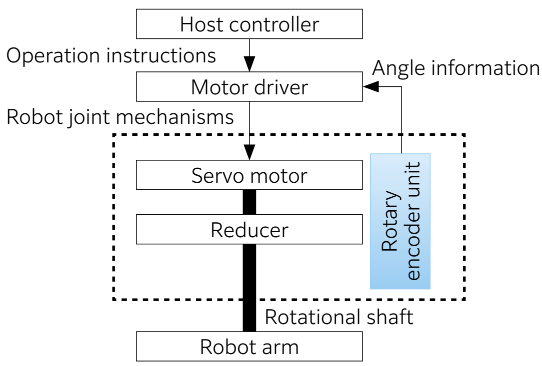
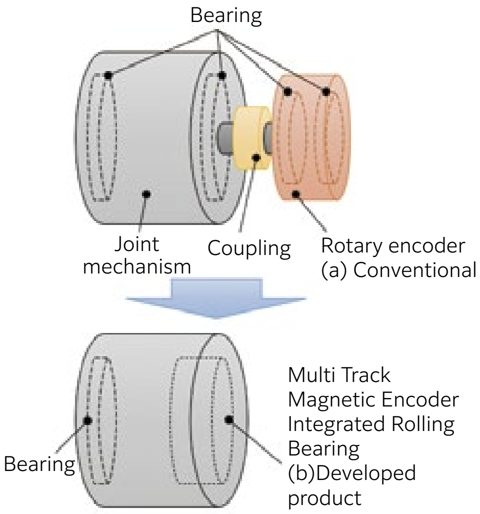


Fig. 4 Schematic drawing of positioning for robot joint mechanisms using the Multi Track Magnetic Encoder Integrated Rolling Bearing

Fig. 5 Rotation sensor bearing (**NTN** conventional product)



Using the developed product enables the rotary encoder to be integrated into the joint mechanism

Fig. 6 Adopting the Multi Track Magnetic Encoder Integrated Rolling Bearing reduces the number of components required for the robot joint mechanism, and makes it more compact

Table 1 Specifications for the Multi Track Magnetic Encoder Integrated Rolling Bearing (deep groove ball bearing 6907)

Item	Specifications
Deep Groove Ball Bearing	6907 (ID35×OD55×10)
Wiring connector height	6 mm (protrusion amount from bearing outside diameter surface)
Encoder unit width	10.5 mm
Multi Track Magnetic Ring	64/63 polar pairs, 1.28 mm pitch
Magnetic sensor IC	iC-MU
Allowable rotational speed	6 000 min^{-1}
Angle resolution	Max. 20 bits
Detection information	Rotational speed, rotational direction, absolute angle
Angle detection error	±0.1°
Power supply voltage	DC 5 V
Current consumption	60 mA
Signal format	ABZ, SPI, BiSS, SSI
Operating temperature range	−25 to +110 ℃

3. Absolute angle detection principles and resolution

3.1 Multi Track Magnetic Ring and magnetic sensor IC

The Multi Track Magnetic Ring **(Fig. 7**, **Fig. 8)** is composed of a core press-formed from thin steel plates and rubber material that contains a magnetic material (hereafter, rubber magnetic material). The rubber magnetic material is adhered to the core by vulcanization. Two magnetic tracks with different number of polar pairs for the N-pole and S-pole are formed on the outer diameter circumferential surface of the rubber magnetic material for the radial magnetization type, and the width surface for the axial magnetization type. For a 64/63 polar pair Multi Track Magnetic Ring, the main track is magnetized with N-pole S-pole 64 polar pairs and the sub track is magnetized with 63 polar pairs.

The magnetic sensor IC arranged opposite the Multi Track Magnetic Ring is equipped with two detection units that face the main track and sub track, and an absolute angle calculation unit. For example, IC (iC-MU) manufactured by iC-Haus can be used **(Fig. 9)**.

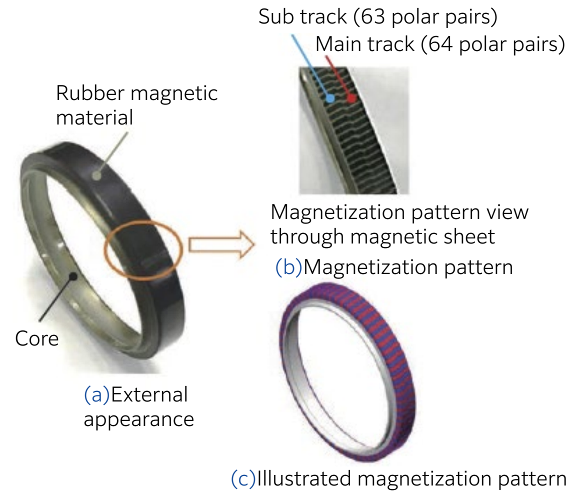


Fig. 7 Multi Track Magnetic Ring: Radial magnetization type

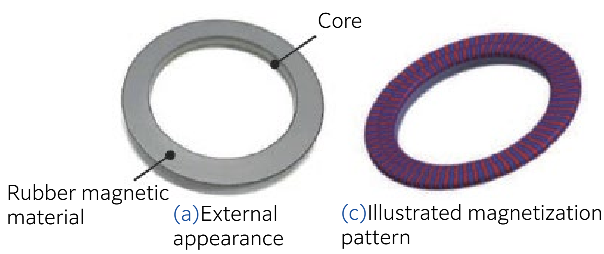


Fig. 8 Multi Track Magnetic Ring: Axial magnetization type

Fig. 9 Illustration of combining the Multi Track Magnetic Ring with iC-MU series (images provided by iC-Haus GmbH)

3.2 Absolute angle detection principles and resolution

This section explains the absolute angle detection principles **(Fig. 10)** and resolution with the 64/63 polar pair Multi Track Magnetic Ring as an example.

For the 64/63 polar pair Multi Track Magnetic Ring, at each rotation the output signal of the period corresponding to magnetization polar pairs 64 from detection unit 1 of the magnetic sensor IC, and magnetization polar pairs 63 from detection unit 2 are obtained. These output signals have a phase difference of one polar pair for each rotation so calculating this phase difference enables the absolute angle to be detected. Thus, on a magnetic pair with 64 polar pairs, it is possible to detect at what polar pair the position lies.

By accurately reading the magnetic strength between polar pairs with the magnetic sensor IC, 12 bit multiplication is possible. Therefore, angle information for one polar pair can be divided into 2^{12} sections, and together with 64 polar pairs (2^6), 18 bit (resolution of approximately 0.0014˚) angle information can be output[8]. Magnetic sensor IC parameters can be configured to also enable up to 20 bit (resolution of approximately 0.00034˚) output.

Angle information output from the sensor is dependent upon the magnetic pitch accuracy. To be able to detect the absolute angle and achieve this kind of high angle accuracy, it is necessary to sufficiently magnetize two magnetic tracks with a different number of magnetized polar pairs. **NTN** has developed original magnetization technology to provide highly precise control of the magnetic pitch for each magnetic pole on the Multi Track Magnetic Ring[9].

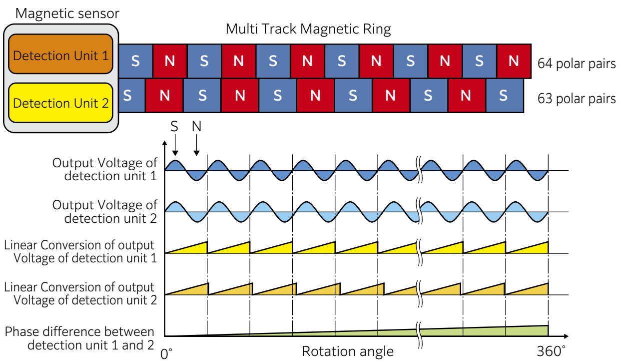


Fig. 10 Absolute angle detection principles

4. Evaluation test

4.1 Absolute angle detection error

The absolute angle detection error was measured for the developed product using deep groove ball bearing 6907. **Table 2** shows the measurement conditions and **Fig. 11** shows the measurement results. The developed product uses both a Multi Track Magnetic Ring and magnetic sensor IC, and these items are attached to a deep groove ball bearing with good accuracy to achieve high accuracy detection of the absolute angle. Under the measurement conditions shown in **Table 2**, an absolute angle detection error of ± 0.1˚ or less was obtained.

4.2 Resistance to electromagnetic noise

The developed product achieves a compact unit composed of few elements as possible, including a deep groove ball bearing, Multi Track Magnetic Ring, magnetic sensor IC and circuit substrate, and contributes towards a more compact and lightweight robot joint mechanism. To investigate its resistance to various noise assumed at the robot joint mechanism, an electromagnetic noise test was conducted. This test results show that the developed product has resistance to EMC Standards (IEC 61000-6-2) for industrial environments[10] (**Table 3**, **Fig. 12**).

Table 2 Absolute angle detection error measurement conditions for Multi Track Magnetic Encoder Integrated Rolling Bearing (deep groove ball bearing 6907)

Item	Conditions
Power supply voltage	DC 5 V
Rotational speed	5 min^{-1}
Measurement angle	360˚
Measurement temperature	Room temperature
Number of polar pairs	64/63 polar pairs

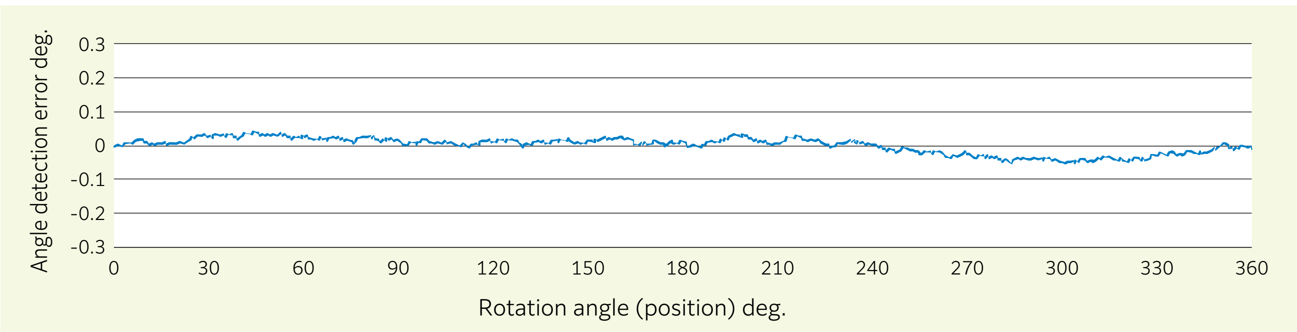


Fig. 11 Absolute angle detection error measurement results of Multi Track Magnetic Encoder Integrated Rolling Bearing

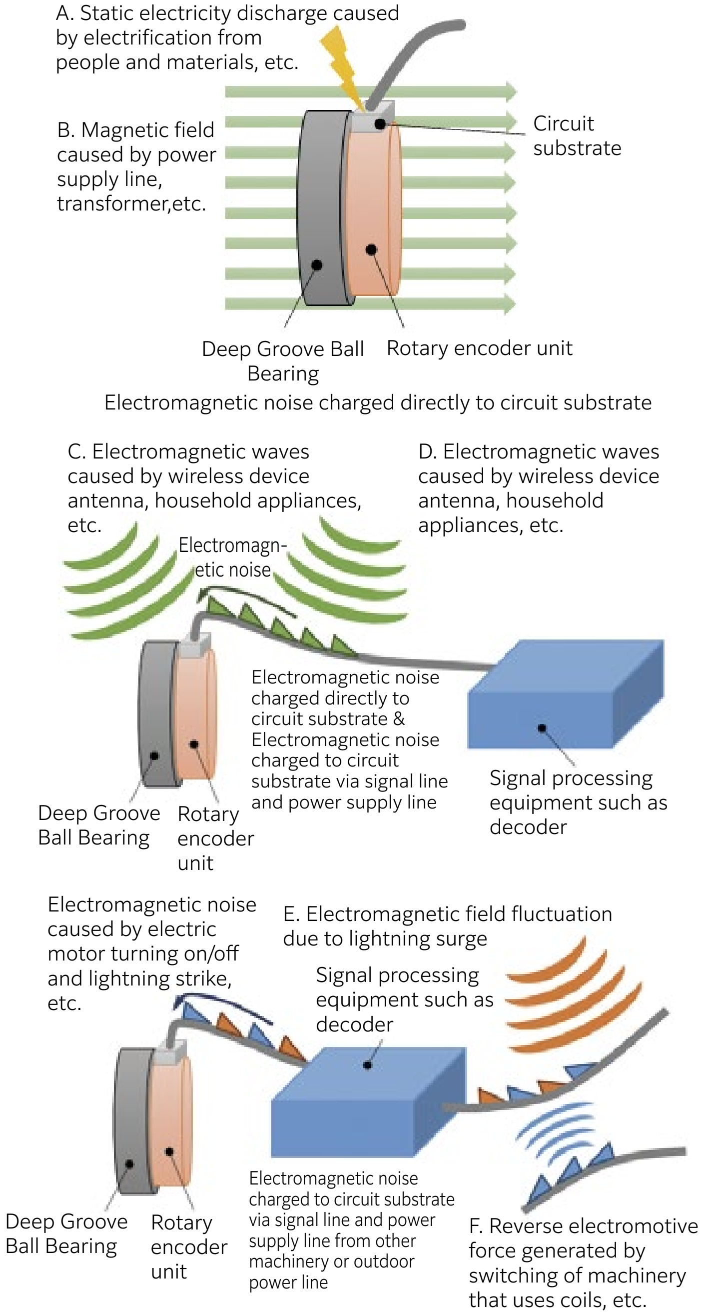


Fig. 12 Types of electromagnetic noise

5. Developed product examples of application

The developed product can be used for compact robot joint mechanisms, such as collaborative robots and service robots using the features introduced in this paper. Additionally, it can also be used in general servo motors by replacing the analog rotary encoders, such as optical rotary encoders and resolvers **(Fig. 13)**.

For example, optical rotary encoders require barriers to prevent the intrusion of dust and oil to the light emitter and light receiver, as well as the internal areas of the encoder so it is difficult to make them compact. Furthermore, resolvers require high accuracy arrangement of many coils in the coil unit which is a key component to achieving high resolution, so they have a complex shape, and it is difficult to make them compact. Additionally, resolvers must have an R/D converter to convert the output signal to digital.

In contrast, the developed product only requires a Multi Track Magnetic Ring and magnetic sensor IC to create the magnetic rotary encoder. This produces a simple structure in comparison with an optical rotary encoder or resolver, which can contribute towards making robot joint mechanisms and servo motors more compact and lighter in weight. The developed product also outputs digital signals, so an R/D converter or similar device is not necessary, so it is easy to make the system compact and lightweight.

Fig. 13 Servo motor

Table 3 Resistance evaluation test to electromagnetic noise

Test No.	Test standards and name	Assumed electromagnetic noise	Test conditions	Results
1	IEC 61000-4-2 : 2008 Electrostatic discharge immunity test	A in Fig. 12	4 kV	No damage possible to conform with EMC standards (IEC 61000-6-2)
2	IEC 61000-4-4 : 2012 Burst immunity test	F in Fig. 12	1 kV	
3	IEC 61000-4-5 : 2014 Surge immunity test	E in Fig. 12	1 kV	
4	IEC 61000-4-8 : 2009 Power frequency magnetic field immunity test	B in Fig. 12	30 A/m (50 Hz/60 Hz)	
5	IEC 61000-4-6 : 2013 Radio frequency conducted disturbances immunity test	D in Fig. 12	10 V 0.15 to 80 MHz	
6	IEC 61000-4-3 : 2006 Radiated, radio-frequency electromagnetic field immunity test	C and D in Fig.12	10 V/m (80 to 1 000 MHz) 3 V/m (1.4 to 6.0 GHz)	

6. Expanding the developed product series

The developed product can be applied to compact robot joint mechanisms such as collaborative robots and service robots. In addition to using the deep groove ball bearing 6907 introduced in this paper, **NTN** plans to expand the series from bearing bore diameter 15 mm to 45 mm.

7. Summary

The demand for robots, including collaborative robots and service robots, is on the increase, and market demands are becoming more sophisticated and diverse.

To respond to the above needs, **NTN** has developed a Multi Track Magnetic Encoder Integrated Rolling Bearing that integrates a deep groove ball bearing and magnetic rotary encoder using Multi Track Magnetic Ring technology. This enables robots that are more compact and lightweight while also reducing man-hours to assemble and setup the robots.

NTN will continue to work on developing products that contribute to further improvements in performance of industrial machinery, including robots, and support the advancement of technology for further enriching people's lives and technology for protecting the global environment.

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