1. Introduction

The recent trend of IoT (Internet of Things), which is to connect “things” to the Internet, is expanding to robotic applications. In developing countries such as China, adoption of industrial robots is increasing due to the rise in labor costs, global price competition, and requirement for product quality. In Japan, labor shortages due to a decreasing birthrate and aging population has become a serious problem. This issue is raising expectations for not only industrial robots in manufacturing, but also for service robots in medical, nursing/welfare, logistics, and security fields.

Japan has provided many industrial robots and their components to the world such as reducers, servo motors, and various sensors. Recent development of industrial robots enabling more complex and advanced operation with artificial intelligence (AI) requires advanced components with high functionality. For precision work, positioning accuracy of the tip of the robot arm requires highly accurate detection of joint angles.

NTN has developed “Multi-track Magnetic Ring” for highly accurate angle detection, applying its precise magnetization technology.

2. Angle detection methods

In general, angle detection devices (hereafter, angle sensors) are broadly categorized as shown in Fig. 1, depending on the detecting methods and output methods. For detecting methods, there are optical methods and magnetic methods. The former detects the light from a light emitting device transmitted through the slit plate or reflected by the reflection plate using a photoreceiver. The latter detects the change of angle by the change of direction and magnitude of the magnetic field. For output methods, there are the incremental method and absolute method. The former repetitively outputs a signal corresponding to the change of angle so that the relative angle can be detected. The latter outputs the current angle information so the absolute angle can be determined. For robots, angle sensors using the absolute method are more suitable since it requires no initialization. For the multijoint robot, which has made remarkable progress in recent years, angle sensors with high resolution and accuracy are required. The servo motor widely used for this application integrates an optical angle sensor (rotary encoder) and a motor with superior properties for these requirements.
3. Magnetic angle sensor

The magnetic angle sensor of the absolute method is configured as shown in Fig. 2, with a pair of N- and S- pole permanent magnets attached to the rotational axis and a magnetic sensor placed against the pair on the fixed side on the coaxial direction. For the magnetic sensor, hall element and MR (Magneto resistance) element are used.

In general, this configuration of using permanent magnet and magnetic sensor is inferior to the optical angle sensor (rotary encoder) in resolution and accuracy. However, it is less expensive and less susceptible to environment such as oil, dirt, and dust. Its application to robots will greatly expand if resolution and accuracy are improved.

4. Development of rotation/angle sensors

NTN implemented volume production of "bearings with rotational sensors" for industrial machinery which can detect both speed and direction of rotation with the incremental method. This method uses a multipole (N/S poles) magnetized ring and magnetic sensor IC to deep groove ball bearings.

NTN also developed "bearings with high resolution rotational sensors" which have higher resolution than "bearings with rotational sensors" by installing a multipole (N/S poles) magnetized ring and magnetic sensor IC with multiple hall elements to deep groove ball bearings. These bearings can provide a maximum of 40 times of incremental output by multiplying the N/S pole pairs by 40 inside the magnetic sensor. Furthermore, NTN also developed "bearings with high resolution rotational sensor of origin signal output type" which can also output origin signals by using a specially patterned N/S multipole magnetized ring.

NTN developed and commercialized "angle sensor units" of the absolute method for construction machinery, which incorporate a permanent magnet and magnet sensor IC facing each other in axial direction within the cast iron or die cast aluminum housing. The sensor technology developed in detection of rotational speed of hub bearings for automotive use is used in broad applications such as rotational speed control of servo motors, angle detection of steering, etc. However, the technology is yet to be applied in robot joints, which require angle detection of high accuracy.

NTN also newly developed the "multi-track magnetic ring" which can detect the absolute angle of rotational shaft with high resolution and accuracy by combining the dedicated magnetic sensor IC (refer to Section 5.2) with the magnetic rotational sensor technology it has developed.

5. About multi-track magnetic ring

5.1 Overview

Fig. 3 (a) shows the appearance of the developed "multi-track magnetic ring."

The multi-track magnetic ring consists of a core metal made of press formed steel sheet and rubber magnetic material. The rubber material is kneaded magnetic material, vulcanized and attached on the outer periphery of the core metal. Two magnetic tracks are formed on the outer diameter periphery of the rubber magnetic material, and as shown in Fig. 3 (b) and (c). The main track is magnetized with 64 N/S pole pairs, and the sub track is magnetized with 63 pole pairs.

In addition to the multiple magnetic ring of "radial magnetized type," shown in Fig. 3, multi-track magnetic ring of "axial magnetized type" was also developed as shown in Fig. 4. Table 1 shows the key specification.
5.2 Principle of absolute angle detection and resolution

Fig. 5 shows the principle of absolute angle detection by multi-track magnetic ring. The magnetic sensor IC placed against the multi-track magnetic ring integrates two detectors facing each magnetic track (detector 1 and detector 2) and absolute angle calculation unit. The iC-Haus GmbH's IC (iC-MU) can also be used.

The multi-track magnetic ring shown in Table 1 obtains output signal with the cycle corresponding to 64 magnetized polar pairs from detector 1 and 63 magnetized polar pairs from detector 2. It can also detect the absolute angle by using the fact that their phase difference changes from 0° to 360° with one rotation. Therefore, it can detect which polar pair position it is in the magnetic track of 64 polar pairs. In addition, this magnetic sensor can provide multiplication of 12 bits by accurately reading the magnetic intensity between the magnetic poles. It is possible to divide the angle information of one polar pair into $2^{12}$. Considering 64 polar pairs ($2^{6}$), it can output angle information of 18 bits (resolution of approx. 0.0014°). Depending on the parameter setting of the magnetic sensor IC, it is possible to output a maximum of 20 bits (resolution of approx. 0.00034°).

In order to achieve such high resolution, NTN is developing proprietary magnetizing technology and controlling the width of each magnetic pole of the multi-track magnetic ring very accurately.

<table>
<thead>
<tr>
<th>Part number</th>
<th>MTR64</th>
<th>MTA64</th>
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<tbody>
<tr>
<td>Magnetized type</td>
<td>Radial</td>
<td>Axial</td>
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<tr>
<td>OD (mm)</td>
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<td>Ø56</td>
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<td>ID (mm)</td>
<td>Ø44</td>
<td>Ø41</td>
</tr>
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<td>Width (mm)</td>
<td>8.2</td>
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<tr>
<td>Weight (g)</td>
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<td>9.8</td>
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<tr>
<td>Number of magnetized polar pairs</td>
<td>64/63 polar pairs (Main track: 128 poles, sub track: 128 poles)</td>
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</tr>
<tr>
<td>Magnet</td>
<td>Rubber magnet</td>
<td></td>
</tr>
<tr>
<td>Core metal</td>
<td>SPCC (rolled steel plate) thickness 0.6 mm</td>
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<tr>
<td>Operating temperature range (°C)</td>
<td>−40 to +110</td>
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</tr>
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</table>

5.3 Features

1) High resolution/high accuracy

As mentioned above, it can output angle information of maximum of 20 bits (resolution of approx. 0.00034°).

Fig. 6 indicates an example of measurement of angle error from the angle sensor combining the multi-track magnetic ring and the magnetic IC sensor described in Section 5.2. This example has an ideal alignment with the least possible installation errors, achieving the angle error of ±0.025°.

2) Hollow structure = Lightweight and compactness

Since its structure is hollow and its diameter is large, it is possible to run cables inside when it is applied to the joints of robots. This will contribute to the compactness and lightweight for robots.

![Fig. 5 Absolute angle detection principle](image-url)
Fig. 7 shows an image of the application of multi-track magnetic ring and magnetic sensor IC to the joints of robots.

A multi-track magnetic ring is fixed on the output stage of the reducer and a printed circuit board implemented with the magnetic sensor IC is installed in the facing position to the magnetic track.

Since the multi-track magnetic ring is fixed on the rotational shaft by press fitting, the installation requires little space contributing small form factor of the joints. The adoption of multi-track magnetic ring is more advantageous than the conventional rotary encoder in terms of installation space. Its compactness will contribute to the increased degree of freedom for designing robots with many rotational axes.

3) Environmental resistance

Environmental resistance of magnetic property of the multi-track magnetic ring is superior to the optical method. It protects against vibration, high temperature, dirt and dust, oil mist, etc. enabling its application in an environment where optical encoders cannot be used.

6. Application for torque sensors

The developed multi-track magnetic ring assumes application for torque sensors in addition to the aforementioned absolute angle detection for robot joints.

High resolution angle detection of 18 to 20 bits can be achieved by using the multi-track magnetic ring. Therefore, torque can be detected by placing multi-track magnetic rings and magnetic IC sensors on both ends of the torsion bar and calculating the torsion amount of the torsion bar from the difference of output angles of each magnetic sensor IC.

Fig. 8 shows an example of the multi-track magnetic ring installed on the actual robot. The multi-track magnetic ring of 64/63 magnetized polar pairs is installed in each joint of the 7-axis robot arm (TOROBO ARM) developed by Tokyo Robotics, Inc. and used for detection of absolute angle and torque. This design was adopted because it achieves a high degree of freedom thanks to the hollow large diameter of the multi-track magnetic ring and accuracy of angle detection.
7. Future development

There are two types of multi-track magnetic rings developed this time: 64/63 polar pair radial magnetized type and axial magnetized type. From now on, development will continue on the smaller diameter type with fewer polar pairs of 32/31 magnetized polar pairs.

In order to respond to the market demand for improved design degree of freedom and various robotic applications, we will continue developing products with higher resolution and accuracy that have a lighter and thinner form factor.

References

5) Ito, Takahashi, Pascal Desbiolles, Cyril Peterschmitt, Shintarou Ueno, High Resolution Sensor Bearing with an Index Signal, NTN TECHNICAL REVIEW No. 78 (2010) 70-76.
9) iC-Haus GmbH. IC-MU off-axis nonius encoder with integrated hall sensors