1. Introduction

Robots can be broadly classified into industrial robots, field robots and service robots (Fig. 1).

Industrial robots are used in many manufacturing factories including automobiles and electrical equipment with demand in relatively simple and repetitive tasks; however, the demand is shifting to a more advanced and automated production process. Japan has a competitive edge in industrial robots and is expected to advance development leveraging its strength. Field robots are engaged in outdoor activities such as on farmland, in the sea and at disaster sites; therefore, robots which perform well at such sites are expected to be developed. Service robots are used in an environment where interaction with people is required, such as at home, at the workplace, and in activities including welfare, healthcare and nursing care. Recently, it is expected that these robots will be rapidly introduced and used in a broader area to increase productivity in the service industry, secure workforce for healthcare/nursing care services, etc.

Robotics is an area that will be adopted globally, as the machines perform tasks in place of human workers, where future growth is highly expected. NTN produces many bearings for robots. In this article, we describe the technical trend of bearings for industrial robots, in particular, their application area and features.

2. Market needs of industrial robot

Industrial robots are required to have not only basic features such as to grab objects at a predetermined position and accurately work on them, but also (1) superior cost performance, (2) accuracy and performance suitable for the required work, easy teaching and correction (accuracy and operability), (3) small and light bodies with small footprints (compact form factor), and (4) contribution for high availability of production line (reliability and maintainability), in order to be broadly deployed in various industrial fields.

In the industry, the demand for automation by adoption of robots is recently increasing in order to deal with the labor shortage in the production lines and to realize stable product quality. The demand for robots in assembly and transfer processes is increasing, for example, from the capital investment in electronics industry due to growing demand of smart

*Application Engineering Dept., Industrial Machinery Division
phones, automotive related industry and IoT (Internet of Things). In addition, the demand for collaborative robots which work with human workers, is also a growing trend and expands the market size for industrial robots. Based on these trends, the requirements for industrial robots such as (1) increase of productivity by reducing tact time, (2) refined workability with improved positioning accuracy and repeatability during work transfers by increasing rigidity of robots, (3) securing work space by reducing the size and footprint of robots and (4) improved maintainability by increasing maintenance intervals, are increasing as the market needs. Table 1 shows the market trend of the recent performance requirements for industrial robots.

Industrial robots are equipped with reducers and gas balancers where bearings are used in moving parts. Based on the aforementioned trends, bearings are required to be smaller in size and higher in rigidity with high-load capacity and long operating life.

Table 1 Market trend of industrial robot

<table>
<thead>
<tr>
<th>Required performance</th>
<th>Recent market needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost performance (robot productivity)</td>
<td>Reduction of tact time</td>
</tr>
<tr>
<td>High accuracy and operability (precise work)</td>
<td>High positioning accuracy Increased repeatability</td>
</tr>
<tr>
<td>Space saving (securing work space)</td>
<td>Compactness</td>
</tr>
<tr>
<td>High reliability and maintainability</td>
<td>Longer maintenance intervals</td>
</tr>
</tbody>
</table>

3. Structure of industrial robots and areas bearings are used

3.1. Structure of industrial robots

The typical industrial robot is the vertical multi-joint robot which moves like a human from the shoulder to the wrist, among many types (Fig. 2). When a robot is operated with heavy objects, each joint drive requires large torque; therefore, reducers are used to amplify output torque of servomotors. A large robot, in particular, is equipped with balancers which produce balance power against the gravity load to complement servomotor power and contribute to energy saving.

3.2. Reducers for industrial robot and areas bearings are used

As robots of different sizes are emerging in recent years, large and small reducers are used accordingly. In this article, we describe (1) eccentric differential reducer for large robots and (2) strain wave gearing reducer for small robots as examples of applications where bearings are used.

(1) Eccentric differential reducer

An example of eccentric differential reducers is Nabtesco Corporation's precision reduction gears RV. Fig. 3 shows the structure of the precision reduction gears RV. This reducer consists of the 1st stage reducer made of a spur gear and the 2nd stage eccentric oscillating reducer with a pin gear mechanism. When the crankshaft rotates, the RV gear moves eccentrically. It rotates in the opposite direction of the input rotation by the difference of number of gears with the internal gear, which is taken out as the output. This mechanism is lightweight and has high rigidity with high tolerance to overload due to the high number of simultaneously engaged gears which also provides low backlash and low vibration with smooth and accurate torque transmission.

This reducer is equipped with needle roller bearings in the eccentric portion of the crankshaft and tapered roller bearings in the journal portion. Each bearing is required to have high rigidity and high load carrying capacity. For the main bearings, thin section type angular contact ball bearings are used in pairs which are required to have high rigidity (moment rigidity) in order to ensure positioning accuracy, which is an important property of a robot.
3.3. Balancer for industrial robots and areas

Bearings are used

---

(2) Strain wave gearing reducer

The strain wave gearing reducer is mainly used as the small reducer mechanism (outer diameter of 100 mm or less). Fig. 4 shows the schematic diagram of its structure. It consists of a thin section type elastic toothed gear made of a thin, elastic metal ring with gear cutting, it incorporates an oval shaft where thin, elastic ball bearings are inserted and the elastic toothed gear is in contact with the thick, rigid internal gear at the major axis. This provides a unique reducing mechanism cleverly utilizing the elastic deformation. The operating principle is shown in Fig. 5. If the internal gear is fixed while the oval shaft rotates clockwise once, the thin section type elastic gear rotates counterclockwise by the difference of the number of gears between the thin section type elastic gear and the internal gear (e.g. thin section type elastic gear has two teeth less) which is extracted as the output. Fig. 5 shows the status where the oval shaft rotated half circle and the thin section type elastic gear moved counterclockwise by one tooth. This reducer has concentric and simple structure with compact form factor and provides a significant reduction ratio of 1/30 to 1/320. Since both teeth are simultaneously engaged like wedges, providing great contact ratio without backlash, the reducer is characterized by averaged gear errors, high angle transmission accuracy, and large torque capacity.

Stress amplitude of tension and compression is repeatedly applied to the outer ring’s outer diameter surface of the thin section type elastic ball bearing, while internally engaging reaction force due to torque transmission is applied in addition to preload due to deformation of the oval part. It is important to provide both fatigue strength against cracking of outer ring and rolling contact fatigue life when designing thin section type ball bearings. Furthermore, consideration is required for the angled shape, surface roughness, residual stress of the surface, etc. in addition to selecting the optimum thickness and thermal treatment specification so that the raceway can tolerate high stress amplitude.

---

3.3. Balancer for industrial robots and areas

Bearings are used

---

Fig. 5 shows an example of the balancer structure for robots. This device is applied to complement the power of the servo motor when the robot arm is extended and contracted for energy saving. Recently, the balancer has moved from coil type to gas type for compactness and high load capacity. In addition, longer maintenance interval is required for high availability.

Self-aligning roller bearings may be used for the rod cylinder support area of this balancer, considering ease of incorporation. For this purpose, it is necessary to select bearings considering abnormal wear and fretting damage, in addition to large load carrying capacity, as it is difficult to form an oil film because of large load and small oscillating angle.
4. Technical trends and characteristics of the bearings for industrial robots

4.1. Technical trends of the bearings for industrial robots

As mentioned above, the main use of the bearings for industrial robots is for reducers and balancers. These bearings are required to have "compactness," "high rigidity," "high load carrying capacity" and "long life." Particularly, compactness of bearings is important; however, that means downsizing of rolling elements due to reduction of cross section, which translates into reduction of rigidity, load carrying capacity and operating life. Namely, the compactness and high rigidity, high load carrying capacity and long operating life are in trade-off relation, so it is important for bearings to achieve compactness without reduction of rigidity, load carrying capacity, and operating life. Table 2 shows the requirements for bearings for industrial robots.

For reducers of robots, while high rigidity, high output torque and high efficiency are required, compactness tends to be required, as well. Angular contact ball bearings for main shafts are required to maintain rigidity and long life, while thin section type is also required. The needle roller bearings for crankshafts are required to pursue space saving within their type, as well as high rigidity and high load carrying capacity. Balancers for robots are required to have high reliability in addition to compactness, while self-aligning roller bearings for rod cylinder support are required to have long life. NTN is conducting R&D for various bearings following the recent technology trend to meet the market demand.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
Areas where bearings are applied & Required performance \\
\hline
Reducer for robot & - Compact (thin section type) \\
 & - High rigidity \\
 & - Long life \\
Crank shaft & - Compact (space saving) \\
 & - High rigidity \\
 & - High-load capacity \\
 & - Long life \\
Balancer for robots (rod cylinder support) & - High-load capacity \\
 & - Long life \\
\hline
\end{tabular}
\caption{Required performance of bearing for industrial robot}
\end{table}

4.2 Compact angular contact ball bearings

NTN designs, manufactures and promotes compact thin section type angular contact ball bearings for main shafts of precision reduction gears. Fig. 7 shows a comparison of cross section with the 79-Series standard type (the outer diameter of the bearings is uniformly designed). The thin section type angular contact ball bearings achieved approx. 30% reduction on the radial direction, approx. 25% reduction on the axial direction in size and approx. 55% reduction of weight.

For this reduction, thinning of the raceway is indispensable; however, the resulting deformation of the raceway (distortion and curve) becomes a challenge. NTN achieved volume production of thin section type angular contact ball bearings by establishing machining technology including optimization of thermal processing conditions for controlling deformation (Fig. 8).
With regard to rigidity (moment rigidity) and operating life (rolling fatigue life) which are in a trade-off relation with reduction, optimal design technology has been established by increasing the distance to the action point of bearings in order to increase the moment rigidity and reducing the contact stress inside bearings to avoid reduction of operating life. Fig. 9 shows the relation between the moment rigidity ratio and operating life ratio against the preload ratio. It reveals that the rolling fatigue life of the thin section type angular contact ball bearings is equivalent to the 79-Series standard type and the moment rigidity is increased by approx. 40% even if they are smaller in size compared to the 79-Series standard type.

**Table 3** shows a comparison between HWT (J) Type and standard type (PK Type). The major feature of the HWT (J) Type is that it enabled increasing number of rollers compared with the PK Type, by eliminating the columns on the inner diameter side of the cage, to achieve high rigidity, high-load capacity and long operating life (**Table 4**).

Furthermore, the roller surface is carbonitrided, strengthening tolerance against damage to the surface due to foreign objects penetrated into lubricating oil or oil film shortage on the raceway, contributing to improvement in reliability and bearing operating life.

**Table 3** High load capacity needle roller bearing

<table>
<thead>
<tr>
<th></th>
<th>Standard type</th>
<th>High-load capacity type</th>
</tr>
</thead>
<tbody>
<tr>
<td>PK Type (Machined cage)</td>
<td>HWT Type (Machined cage)</td>
<td>HWTJ Type (Pressed cage)</td>
</tr>
<tr>
<td><strong>Limited number of rollers due to columns on the inner diameter side</strong></td>
<td><strong>More rollers can be placed as there are no columns on the inner diameter side</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Table 4** Comparison of performance for PK type

<table>
<thead>
<tr>
<th>Item</th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of rollers</td>
<td>+20-35%</td>
</tr>
<tr>
<td>Basic static load rating</td>
<td>+20-35%</td>
</tr>
<tr>
<td>Basic dynamic load rating</td>
<td>+15-25%</td>
</tr>
<tr>
<td>Rolling fatigue life</td>
<td>×1.5-2</td>
</tr>
<tr>
<td>Rigidity</td>
<td>+15-25%</td>
</tr>
</tbody>
</table>

**4.4 Long operating life for self-aligning roller bearing**

NTN deploys "ULTAGE" Series "EA Type" as the self-aligning roller bearings for rod cylinder support of robot balancers in the market.

The "EA Type" has improved the load carrying capacity (basic dynamic load capacity) by max. 65% (**Fig. 10**), achieving top level performance (**Fig. 11**).

In addition, the "ULTAGE" Series features sealed type (WA Type) with seals on both sides (**Fig. 12**) in its line-up, as well, which allows enclosing special grease with superior wear resistance and fretting resistance, contributing to improvement of maintainability and bearing life.
5. Summary

NTN produces many bearings for robots. In this article, we described the technical trends and features of bearings for industrial robots.

It is expected that the robot demand will grow along with rapid development of the service fields, and robots are expected to work closely with humans.

NTN is poised to continue contributing to the development of robots by product development and improvement of bearings for robots.

References