1. Introduction

While roller bearings for general use are regulated by standards such as ISO and JIS, roller bearings for supporting vehicle wheels (axle unit bearings) have gone through significant transitions over the years. Also, in recent years restrictions on size, weight, fuel consumption, and environmental consciousness of automotive components have been imposed. The axle unit bearings have evolved to meet those requirements. In this article, the history of these developments is discussed, focusing on reduction of weight and fuel consumption (low torque) of axle unit bearings.

2. Overview of Market Demand for Axle Unit Bearings

The design specifications of axle unit bearings are diversely based on automotive manufacturer needs (mounting methods, allowable space and bearing size, bearing load carrying capacity, low torque performance, muddy water resistance, rigidity and strength, etc.). Their past and current requirements can be categorized as follows:

a) Ease of assembly
b) Simplification or elimination of bearing clearance adjustment
c) Compact, lightweight and large load carrying capacity
d) Maintenance-free
   Particularly, elimination of greasing operation and external seal for sealed bearings
e) Reduction of quantity of components
f) Overall cost reduction including bearing units, secondary components and labor cost

Responding to the above requirements, NTN has been developing and marketing the production of the 1st generation, 2nd generation and 3rd generation products (GEN1, GEN2 and GEN3) for approximately 40 years.

In addition, environmental regulations have been introduced in many countries with continuous enhancements. This demands the improvement of fuel efficiency to reduce CO2 emissions. Therefore, lightweight and low torque products are required for axle unit bearings, in addition to the above mentioned requirements.

3. History of Axle Unit Bearings

3.1 History of Bearing Type

Until the 1970s, placing two single row roller bearings was the norm. However, the single row roller bearing had limitations for reducing the weight and size. Therefore, the evolution of unitized products was done to ease assembly, which had the potential to accommodate the weight and packaging requirements.

The first of such products were the Sealed Double Row Angular Contact Ball Bearing (Angular Unit) and Sealed Double Row Taper Roller Bearing (Tapered Unit), then named GEN1 bearings. These were widely used in the themed to late 1970s. In the 1980s, the bearings were unitized with their secondary components, such as hubs and housings (knuckles) to reduce the number of components. This also aided in the efforts to reduce weight, which eventually resulted in the GEN2 bearing.

The aim to further reduce the amount of individual components led to the creation of the GEN3 bearing. Because the GEN3 bearing encompassed more components than the previous GEN2, the installation of the axle unit bearing on the vehicle assembly line was simplified.

Table 1 shows the transition and characteristics of NTN’s axle unit bearings by generation, including the time when two single row bearings were used (before unitization efforts began).
History of Development of Axle Bearings Aiming at Low Fuel Consumption

Through the multiple generations of bearings, more secondary components have been incorporated into the single product. This helped reduce the total number of individual components contributing to a more compact design and overall lighter axle weight. Similarly, as the axle unit bearings evolved with further unitization, press fitting the inner/outer rings onto the secondary components is no longer necessary. On driven bearings, fixing the inner ring by swaging it makes preload management easier resulting in significant reduction of variability. This improved preload optimization to achieve reduction of running torque.

3.2 Development of Next Generation Hub Joint
After the creation of the GEN3 for production, NTN completed the development of the next generation axle unit bearing: the GEN4. This bearing combines the axle unit bearing with the constant velocity joint (CVJ). This technology has not been adopted because it requires significant modification to the vehicle assembly lines at the auto manufacturers.

Therefore, NTN developed a new assembly method for CVJ and axle unit bearings, which can be done without changing the assembly lines at the auto manufacturers. The Press Connect Hub Joint (PCS H/J) method achieves a significant reduction in weight (Fig. 1).

Conventionally, the CVJ and axle unit bearing are connected with a spline and tightened with a nut. The spline teeth are generally designed for interference fit with the helix angle to eliminate backlash, which requires a long spline fit length. The new press connect fit method finishes securing the spline by tightening a bolt, which results in a tighter interference fit than the CVJ stem spline on the hub bearing bore diameter. This enables the torque to be applied to the entire spline area, resulting in significant reduction of spline fit length.

The adoption of the PCS H/J method achieves about a 65% reduction in CVJ stem length and a 12% reduction in weight (max.). This is due to the hollow structure of the hub ring inner diameter, conversion of nut to bolt, etc., and no spline fit backlash.

3.3 Development of Lightweight Bearings
As mentioned above, NTN has been reducing the size and weight of the entire axle structure through multiple generations of increasingly unitized axle unit bearings. However, after the adoption of the GEN3 as the mainstream product, further weight reduction of the bearing was required, but unitization has become more difficult.

Table 1 Transition and Characteristics of NTN’s Axle Unit Bearings by Generation

<table>
<thead>
<tr>
<th>Generation</th>
<th>Conventional</th>
<th>GEN1</th>
<th>GEN2</th>
<th>GEN3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of production</td>
<td>- 1970s</td>
<td>Mid - 1970s</td>
<td>1983 -</td>
<td>Mid - 1980s -</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structure</th>
<th>Driven Wheel</th>
<th>Non-Driven Wheel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature</td>
<td>• Two single row roller bearings.</td>
<td>• Combined two single row roller bearings.</td>
</tr>
<tr>
<td>Ease of Assembly to Vehicles</td>
<td>☆</td>
<td>☆☆</td>
</tr>
<tr>
<td>Compactness</td>
<td>☆</td>
<td>☆☆</td>
</tr>
<tr>
<td>Rigidity</td>
<td>☆</td>
<td>☆☆</td>
</tr>
<tr>
<td>Preload Control</td>
<td>☆</td>
<td>☆☆</td>
</tr>
<tr>
<td>Running Torque</td>
<td>☆</td>
<td>☆☆</td>
</tr>
</tbody>
</table>

Order of Superiority: Excellent ☆☆☆☆ > ☆☆☆☆ > ☆☆☆ > ☆ Poor
Requirements for the GEN3 axle unit bearing, as the strength member, are different from those for the individual bearing, in terms of strength of hub ring, strength of outer ring, overall bearing rigidity, etc. Weight reduction was required while maintaining these strengths, particularly with GEN3. The weight of the hub ring and outer ring account for more than a half of the entire unit, so optimal design of these components is very important for reducing weight.

NTN uses FEM analysis to determine weight abatement while maintaining the strength and rigidity to satisfy the required functionality. In the past, the optimal shape was developed using topology optimization\(^4\). An ultra-light hub bearing shape shown in Fig. 2 was also developed. Therefore, NTN employs the accumulated technologies to provide the optimal shape for the minimum weight, while meeting the required specifications.

**3.4 Development of Torque Reduction**

Reduction of torque has always been required for axle unit bearings to improve the vehicle fuel efficiency. However, the requirements are becoming stricter since many countries introduced environmental regulations. NTN has developed various low torque products to respond to market demands for hub bearing applications. Fig. 3 shows the progression of hub bearings reducing torque.

The torque of axle unit bearings consists of rolling resistance from the rolling balls that follows the rotation of the bearing and the sliding resistance of the seal, which is equipped to seal the bearing. Each represents approximately 50% of the entire torque. Therefore, reducing them is the general approach to reducing the overall torque.

**3.4.1 History of Grease Development**

The rolling resistance of the bearing is determined by the bearing design and the grease contained in the bearing. The bearing design is optimized to satisfy the customer’s demands. The grease contained in the bearing has been developed over many years based on the needs of the customers and the market.

![Fig. 2 Shape of developed product by topology optimization](image)

![Fig. 3 History of development of hub bearings](image)
The standard grease used in production currently is based on that used for GEN1 production, with improvements made to better its rust resistance properties. In the mid-2010s low friction grease was developed and used on vehicles requiring lower torque. In 2019 the ultra-low friction grease was created further reducing torque. The difference between the three greases are the base oils. The standard grease uses mineral oil, the low friction grease uses a mixture of mineral oil and synthetic oil and the ultra-low friction grease uses synthetic oil. Adopting superior base oil can reduce the viscosity resistance in the low to mid temperature range and, in turn, reduce torque. NTN has been optimizing, not only the base oil, but also the thickener and additives which compose the grease, improving the torque property and other grease properties.

3.4.2 History of Seal Development

Various elements of seal sliding resistance have been developed and introduced to the market, such as the optimization of the seal design structure, rubber material, lip contact surface, lip rigidity, etc. without degrading the seal property. By incorporating these elements, the seal torque has been significantly reduced compared to previous seals.

Further torque reduction can be achieved by reducing the number of lips in contact with the rotating components. However, this would degrade the seal function. A new seal was developed adopting a labyrinth structure to combat these issues.

For the driven wheels, CVJ does not have to be inserted in the inner diameter. Therefore, a design that seals the inboard side (vehicle side) with a cap is implemented, as shown in Fig. 4, which significantly reduces torque by eliminating one of the two seals of the conventional unit.

4. Summary

NTN has been working to develop axle unit bearings for over 40 years and has expanded its market with the merger of NTN-SNR in 2008, which has enabled its market share has grown to the top. By continuously working to meet the market’s needs, we are able to offer products with lower weights and torque than in the past while maintaining reliability. We are excited to continue our development of the next generation of products with new ideas for further reduction of weight and torque.

In this article, we have reviewed the history of axle unit bearings development focusing on reduction of weight and torque. We owe this to the efforts of our pioneers, which we are very proud of, and hope to continue these efforts to construct vehicles with greater functionality and comfort.

References

Fig. 4 Example of sealing cap structure