HUBLFT: Hub Unit for Low Friction Torque

S. YAMANE T. OGIMOTO

Hub Units are used worldwide as automobile wheel bearings. Through careful consideration of the function and performance of components such as grease and seals, we have completed the development of a low torque Hub Unit called "HUBLFT". This paper will introduce the factors that have been redesigned to give this product top performance.

Key Words: *Axle bearing, low torque, grease, seal, hub unit*

1. Introduction

As represented by COP (United Nations Convention of the Parties for Climate Change), alively debate is ongoing throughout the world regarding actions to protect the planet's environment. Year after year, the automotive manufacturing industry is being required to comply with increasingly stringent fuel efficiency requirements in line with CO_2 emissions regulations aimed at preventing global warming. Particularly with regards to Europe, a regulation requiring CO_2 emissions to be reduced from 130 g/km in 2015 to 95 g/km by 2021 is already in effect and there is talk of reducing it even further to 70 g/km. The fuel efficiency requirements for countries and regions other than Europe also show signs of becoming stricter, and it is believed that automotive manufacturers will continue raising the bar for their fuel efficiency targets. In order to contribute to better fuel efficiency, JTEKT is striving to not only reduce the weight of its hub unit, but also to reduce their rotational torque. By determining the individual factors that influence the rotational torque of hub units and applying specific measures to reduce each of them, JTEKT has developed a hub unit with superior low torque called HUBLFT. This paper introduces the low-torque technologies employed by HUBLFT.

2. Analysis of Rotational Torque

As **Fig. 1** shows, the hub unit is a unitized bearing positioned inside a vehicle's wheel comprised of a bearing which includes rolling elements and inner/outer ring raceways, and a flange section which joins the unit to the vehicle. This structure enables the hub unit to support the vehicle's weight while facilitating smooth rotation of the wheel (**Fig. 2**). The bearing is also equipped with seals to prevent muddy water thrown up by vehicle tires from penetrating in to the bearing and to prevent lubrication

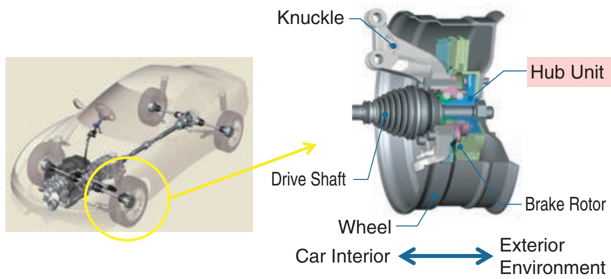

Fig. 1 Structure of axle assembly

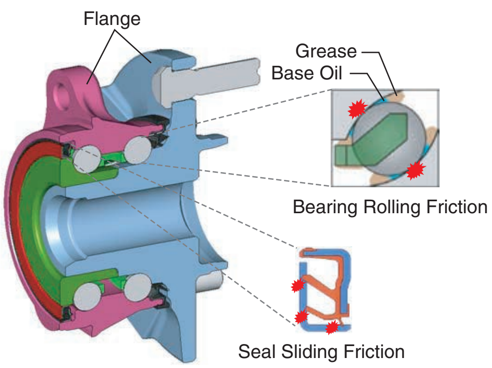

Fig. 2 Hub Unit

grease from leaking out of the bearing. These seals ensure that the bearing is maintenance-free and rotates smoothly for the life of the vehicle.

Two major factors contributing to rotational torque are rolling friction of the bearing and sliding friction of the seal. Depending on vehicle weight, the rolling element PCD (pitch circle diameter) and other hub unit specifications change, making the exact contribution ratio between these factors vary slightly, however these two major factors are considered to each separately contribute approximately 50% to friction loss.

3. Methods to Reduce Rotational Torque

3. 1 Rotational Torque of the Bearing

The bearing section of the hub unit operates under an axial load called “preload”. Preload is necessary to maintain stable bearing life and good vehicle maneuverability, or in other words, to secure bearing rigidity. Preload is applied by either clinching the shaft end or tightening with a nut. One measure that would be effective in reducing bearing friction loss would be to reduce preload, however this would significantly impact vehicle steering. In order to reduce friction loss without such a trade-off, and assuming no change to bearing specifications, the factors that determine bearing rotational torque were analyzed. **Figure 3** shows the results of this analysis. Bearing rotational torque can be partitioned into grease shearing friction, base oil viscous friction and rolling-sliding friction. The following sections introduce the measures used to reduce the torque contribution attributed to each of these factors and the corresponding results.

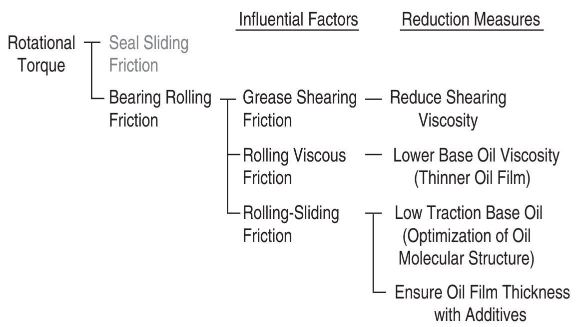

Fig. 3 Influential factor analysis and measures for reduction of rotational torque

3. 1. 1 Grease Shearing Friction

The friction generated when grease itself moves due to the difference in the relative speeds of the rolling elements to that of the cage and inner/outer rings is called “shearing friction”. Conventionally, hub units use grease that is parted by the passage of the rolling elements along the raceway and has channeling properties which stop it from returning back to the raceway. However, due to back pressure from the passage of the rolling elements, the expelled grease does return to the raceway and it is believed that the grease and rotating elements (rolling elements and cage) continue to make contact.

Shearing viscosity is a characteristic that describes the shearing friction generated when grease moves. One approach to reducing shearing viscosity would be to change the grease consistency (soften the grease) however this has significant disadvantages including downwards flow when the grease is sealed into the hub unit and grease leakage from the seals. As such, JTEKT developed a grease with reduced shearing viscosity but with the same consistency as that of conventional grease. **Figure 4** shows a comparison between the shearing viscosities of the developed grease and conventional grease, respectively. Shearing viscosity of the developed grease was shown to have been reduced throughout all speed ranges. The reduction of shearing viscosity at low speeds was enabled by adopting a special thickener while reduction of maintaining the same consistency was achieved by reducing the amount of thickener overall. Meanwhile, the shearing viscosity at high speeds is thought to have decreased due to the use of a base oil with a lower viscosity since it is widely recognized that the dynamic viscosity of the base oil is a dominant factor at high speed, and this is explained further in the following section.

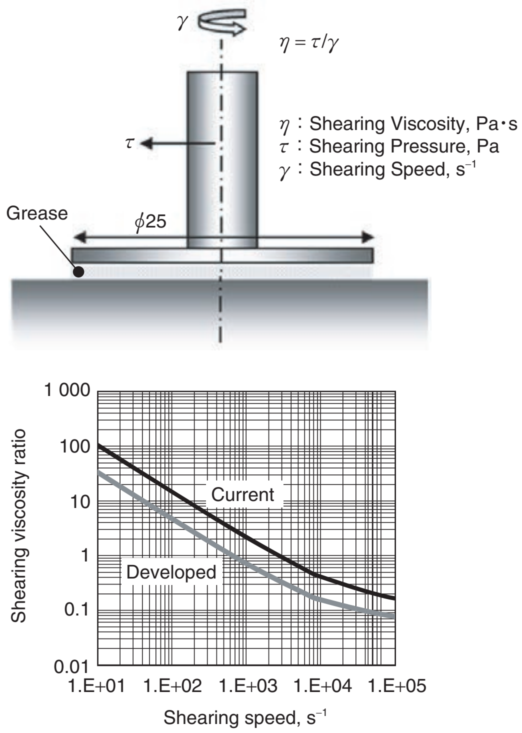

Fig. 4 Comparison of shearing viscosity

3. 1. 2 Rolling Viscous Friction

According to EHL (elasto-hydrodynamic lubrication) theory, the rolling of rolling elements is facilitated by an oil film which forms between the rolling element and raceway, and the friction of passing through this oil film is known as viscous friction. **Figure 5** shows the calculated results of friction loss excluding grease shearing friction. The rotational torque of hub units and other bearings increases the faster they rotate and for that reason, viscous friction which is the greatest contributor to rotational torque at high speeds was reduced as much as possible.

The dynamic viscosity of base oil is a dominant factor in viscous friction, so lowering dynamic viscosity was a priority, however careful consideration was also given to maintaining oil film thickness even under high bearing surface pressure and with these factors in mind the reduction of viscous friction was successfully achieved.

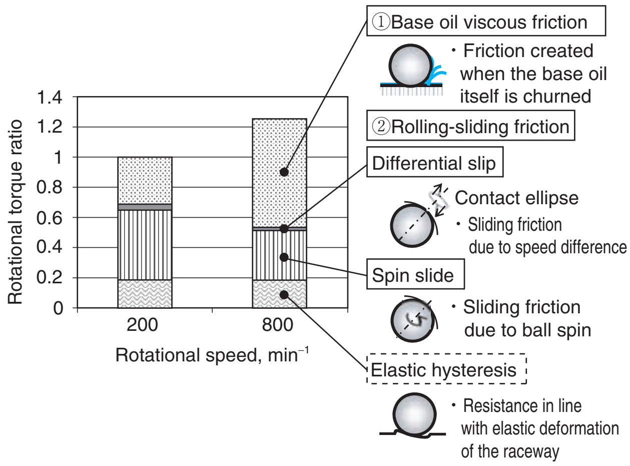

Fig. 5 Breakdown of bearing torque (calculated)

3. 1. 3 Rolling-Sliding Friction of the Bearing

Rolling-sliding friction is divided into spin slide friction and differential slip friction however both of these can be categorized as sliding friction between the balls and raceway. JTEKT focused on the friction coefficient, μ, to reduce this sliding friction.

As a measure to lower the friction coefficient, the base oil type, i.e. the base oil molecular structure was revised. **Figure 6** shows the results of a traction coefficient comparison of different types of base oils. Synthetic hydrocarbon oil and the conventional paraffin-based mineral oil were tested in a dual cylinder traction coefficient measuring apparatus. Results show that the synthetic hydrocarbon oil had a traction coefficient around 30% lower than the conventional paraffin-based mineral oil. In contrast to hydrocarbon oil which is well known for its smooth linear molecular structure, mineral oil, a typical example of the paraffin-based oils conventionally used, has an uneven three-dimensional molecular structure. The researchers demonstrated that its unique molecular structure lead to synthetic oil's ability to reduce its traction coefficient.

Apart from the molecular structure of the base oil, a correlation also exists between the μ characteristic and the thickness of the oil film that forms between the rolling element and raceway. According to the aforementioned **Fig. 5**, rolling-sliding friction makes a smaller contribution to rotational torque during high-speed rotation than it does during low speeds. In order to reduce this friction at low speeds, or in other words, if a measure was adopted to make oil film thicker only at low speeds, it is believed that there would be little impact on rotational torque during other times. **Figure 7** compares the oil film thickness of the developed grease with that of the conventional grease. It is a well-known phenomenon that the oil film thickens at low speeds less than S = 1 m/s due to the thickener. However, additives able to thicken the oil film more than the thickener alone could were incorporated to ensure a thicker oil film at low speeds in the developed grease, thus successfully reducing rolling-sliding friction more than conventional grease.

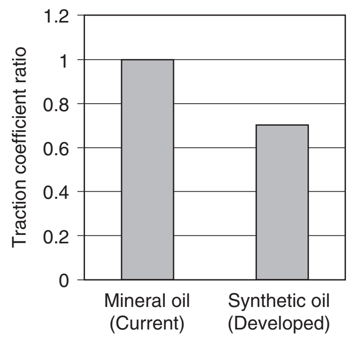

Fig. 6 Results of comparison of traction coefficient

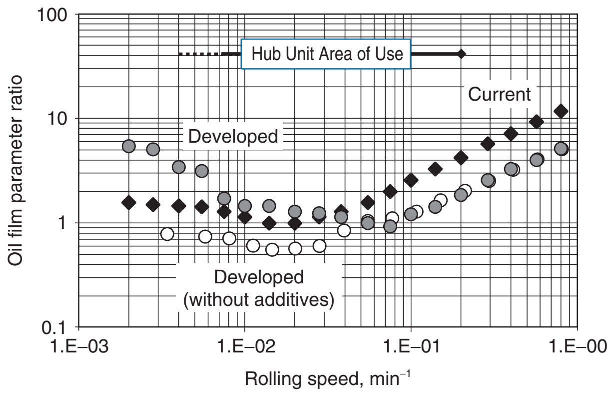

Fig. 7 Comparison of oil film parameter

3. 2 Rotational Torque of the Seals

The seals used in bearings are critical components required to maintain hub unit functions and consequently reducing friction must be done without affecting sealability. Equation(1) is used to calculate seal sliding torque. Here, T_s is seal sliding torque, μ is friction coefficient, P_r is seal lip tension and D is the sliding diameter of the seal lip. Seal sliding torque, T_s, is proportional to the friction coefficient, μ, and seal lip tension, P_r. Below the measures used to reduce these two items are described.

$$T_s = \mu P_r \frac{D}{2} \quad (1)$$

First, the measure to reduce seal lip tension will be explained. As shown in **Fig. 8**, conventional seals are configured with a radial lip and an axial lip. In light of the space limitations imposed on seals, the radial lip has to be short dictating a rigidity that leads to high seal torque. For this hub unit development, the radial lip was replaced with another axial lip to create a double axial lip configuration comprising two long, soft lips. Furthermore, by leveraging JTEKT's own original super-elastic analysis and using the stress-strain diagram for the seal rubber material, seal lip tension was optimized and seal torque was reduced. Finally, when tested under JTEKT's rigorous conditions, adopting the double axial lip configuration and optimizing seal lip tension had the synergistic effect of doubling sealability against muddy water penetration.

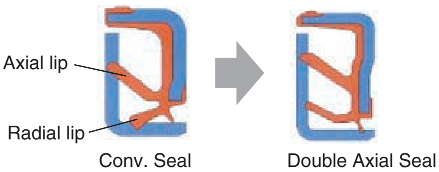

Fig. 8 Comparison of seal lip

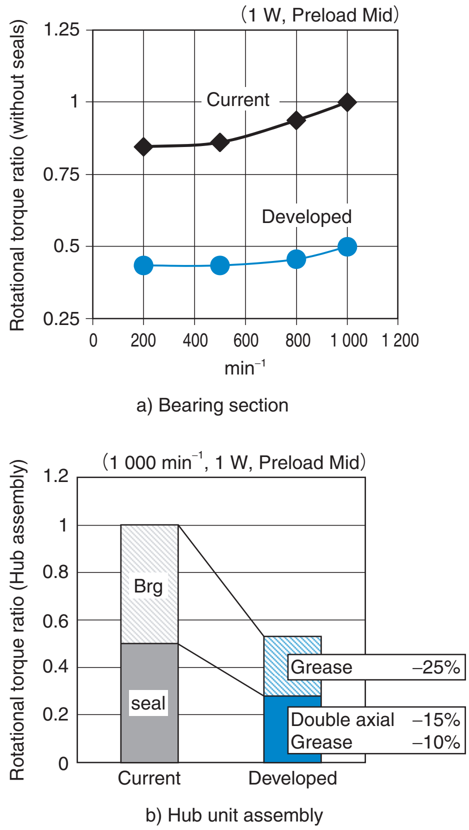

Fig. 9 Results of comparison of torque

Meanwhile, efforts were also exerted to improve seal grease in order to reduce the friction coefficient, μ. In the past, there was concern that mixing different types of grease would alter grease properties; therefore the same grease was used for the seal as that used in the bearing. However, it is now known that, due to the seal contact surface pressure being small, and having a relatively low rotational speed, the fluid lubrication zone is stable. Independently from the bearing grease, an ultra-low-viscosity base oil grease was adopted specifically for the seal.

Regarding the aforementioned concern of mixing different grease types, even when mixed there were no apparent changes to consistency or other properties when the bearing grease and the grease developed for the seal. This was confirmed in an infrared analysis (IR), where no changes in composition were found. This has led to the conclusion that the affinity between the two greases is not a problem.

4. Results Verification and Vehicle Compatibility

Results verification was done using an actual hub unit and the extent of the torque reduction produced by the developed bearing grease were confirmed. The results are shown in **Fig. 9 a)**. The hub unit used for testing employed a seal with the tip of the lip cut in order to eliminate the impact of the seal's sliding torque. In JC08 mode, which has a maximum speed of 800 min^{-1} (equivalent to 80 km/h), torque was confirmed to be 50% less than that of conventional bearings. Equivalent reductions were also confirmed at other rotational speeds. Furthermore it was observed that the improvement in low-temperature flow point through the shift to synthetic base oil was also effective in reducing start-up torque at extremely low temperatures.

Additionally by adopting a double axial lip for the seal and improving seal grease, as illustrated in **Fig. 9 b)**, at a rotational speed of 1 000 min^{-1}, the two measures contribute to reducing torque by 30% and 20% respectively when considering the seal in isolation (or 15% and 10% when considering the hub unit assembly as a whole). As was the case with the bearing grease, torque reductions as a result of these measures were also confirmed at other rotational speeds.

Regarding vehicle compatibility, the developed grease demonstrated equivalent or superior performance compared to conventional grease for all criterion as outlined by JTEKT's robust tests guidelines, including those for bearing fatigue life (as well as fatigue life given water-choked grease, low-speed fatigue, high-speed durability, muddy-water seal durability tests, etc.).

5. Effects other than Torque Reduction

In line with a growing demand for passenger vehicles on a global scale, more vehicles are being transported to extremely cold regions such as Russia. Vibration during vehicle transportation may result in fretting wear on the bearing raceway and lead to problems such as noise and vibration during vehicle operation.

Under JTEKT's test conditions low-temperature fretting wear is reduced by 70% when the developed bearing grease is used. Given that base oil acts as a median to supply additives to the raceway and that the shift to synthetic base oil has enhanced the low-temperature flow point, the grease rheology (flow) at extremely low temperatures has improved. Wear amount is believed to have been reduced due to this improvement coupled with the selection of additives with good absorptivity and reactivity at extremely low temperatures. By preventing fretting wear of bearings when vehicles are being transported in extremely cold regions, it is expected that damage during non-operational states will be eliminated.

In regards to seal grease as well, maintaining the rheological properties of the grease and its base oil at low temperatures is important in sustaining sealability in extremely cold regions. As was the case with the grease used in the bearing section, it was found that by improving the low-temperature flow point through a shift to a synthetic base oil satisfactory rheological properties were preserved even in low-temperature environments, and sealability was enhanced.

6. Conclusion

In order to develop a superior low-torque ball hub unit, JTEKT focused on the grease of the bearing section and seal, which had never before been investigated. After clarifying the factors influencing the rotational torque of hub units a low-viscosity, synthetic base oil was adopted as a reduction measure. As a result and with the trade-offs associated with the adoption of low-viscosity base oil being suppressed through optimized additive type and amount, and by adopting a double axial lip seal and optimizing seal lip tension as well, overall hub rotational torque was reduced by 50%.

In particular this process of grease development, and through conducting various verification tests including those for bearing fatigue, fretting wear and additive coating efficacy, has provided new insight about the behavior of grease during bearing rotation. With emissions regulations growing increasingly stringent for not only passenger vehicles, but also for SUVs, pickup trucks and so on, JTEKT wishes to apply this technology to the taper roller hub units used in such vehicles to help further improve fuel efficiency for all vehicles and protect the planet's environment.

References

1) R. NAKATA: Grease Lubrication Technology for Sliding Automobile Parts JTEKT ENGINEERING JOURNAL, No.1011E (2014) 25-30
2) K. YOSHIZAKI: Grease Lubrication Technology of Rolling Bearings JTEKT ENGINEERING JOURNAL, No.1010E (2013) 27-32
3) M. TAKIMOTO: Technical Development of Automotive Wheel Bearing Seals (Muddy-Water Resistant Seal, Low-Temperature Environment Seal, and Super Low-Torque Seal) JTEKT ENGINEERING JOURNAL, No.1008E (2011) 64-69


S. YAMANE* T. OGIMOTO**

* *West JAPAN Technical Center, Bearing Operations Headquarters*
** *Experiment & Analysis Dept., Bearing Operations Headquarters*