Technical Development of Automotive Wheel Bearing Seals (Muddy-Water Resistant Seal, Low-Temperature Environment Seal and Super Low-Torque Seal)

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With regard to automotive wheel hub units, customers traditionally have sought improvements such as longer service life, higher rigidity and reductions in size and weight. But in recent years, their demands for such seal-related performance as muddy-water resistance and lowered torque have been increasing. The seal is an important hub unit component that functions to prevent water or foreign matters from entering into the bearing. This report introduces a seal-periphery rubber molding process for preventing muddy-water intrusion, a low-temperature seal for securing sufficient muddy-water resistance in cold regions, and a super low-torque seal with muddy-water resistance.

***Key Words**: hub unit, seal, muddy water, low torque, low temperature*

1. Introduction

Bearing seals are generally used for preventing foreign matter from entering into bearings or preventing leakage of lubricating grease. Seals mounted in automotive hub units, especially for SUVs or commercial cargo trucks, are used in all kinds of severe outdoor environments from deserts to very cold regions. Therefore, seals should protect hub unit bearings against intrusion of foreign matter like dust –archenemy of bearings– or water including muddy-water or anti-freezing agents (like calcium chloride) even when corrosion occurs at peripheral portions of seal fitting. One possible solution is to increase the interference of the seal lip, but this may cause an increase in friction torque or temperature, which may promote wear of the seal lip, resulting in reliability reduction of seal and hub unit. Proper approaches are therefore needed.

On the other hand, while the external environment for hub units for passenger cars is not so severe as that for SUVs, muddy-water resistance is very important. Furthermore, in order to cope with growing demands for global environment protection, it is also necessary to contribute to reduction of CO_2 emissions by lowering seal friction torque while maintaining muddy-water resistance.

This report introduces technology for prevention of muddy-water intrusion into automotive hub units designed for various operating conditions of vehicles, a seal for low temperature environment and a super low-torque seal suitable for global environment protection.

2. Prevention of Muddy-Water Intrusion

2. 1 Muddy-Water Intrusion Route into the Bearing

Sealing performance of bearings is ensured by seals which have an important function of maintaining lubrication in the bearings and keeping reliability. There are two routes of muddy-water intrusion into bearings after muddy water reaches the hub unit from the wheel components. One is through the fitting portion of the seal with outer ring (intrusion due to capillary phenomenon) and the other is through the sliding contact portion of the seal lip (intrusion due to seal lip wear). Details are shown in **Fig. 1**.

Normally, lip configuration, lip angle and interference (between a seal lip and a hub shaft) at seal lip portion are optimally designed for maintaining sufficient sealing performance. However, further improvement is required to prevent water intrusion through the fitting portion of the seal outer diameter. A study has been made to obtain optimal design specifications by testing.

For the purpose of preventing water intrusion through the fitting portion of the seal outside diameter, seal rubber is molded on the seal outside diameter at the same time as seal molding process. In some cases, however, it has been reported that under extremely heavy amounts of water exposure, water happened to enter bearings through the metal fitting area of the molded rubber portion, resulting in insufficient bearing lubrication and bearing noise. **Figure 2** shows an example of water intrusion.

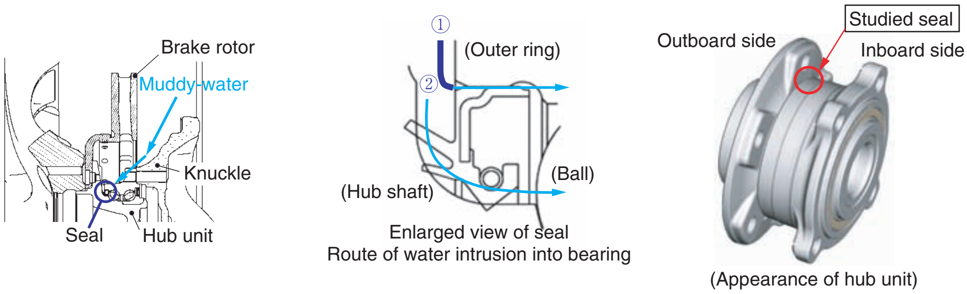

Fig. 1 Intrusion route of muddy-water into hub unit

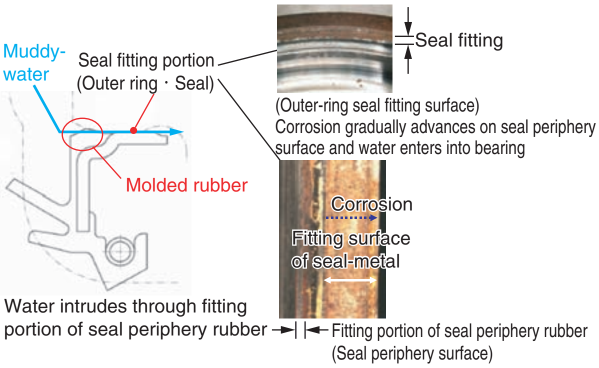

Fig. 2 Water intrusion through seal fitting portion

JTEKT has engaged in continuously improving sealing performance of bearings in order to provide such bearings that can be used even under severe exposure to water. An approach is hereunder introduced.

2. 2 Measures against Muddy-Water Intrusion

Design optimization of seal fitting portion was studied based on the results in the field for the purpose of achieving 50% reduction in muddy-water intrusion, compared to current levels of intrusion. Optimal specifications were determined based on a design of experiments and the effect was verified by a cyclic corrosion test.

2. 2. 1 Optimal Specifications

With regard to the four factors whose contribution ratio to the improvement of muddy-water resistance is considered high, some combinations of specifications were selected as shown in **Table 1**.

Table 1 Specifications

Item	Contents	Specifications
1	Fitting interference of seal periphery rubber (Axial direction)	Totally 3 patterns
2	Fitting length of seal periphery rubber	Totally 3 patterns
3	Roughness of outer-ring seal fitting surface	Totally 2 patterns
4	Roundness of outer-ring seal fitting surface	Totally 2 patterns

2. 2. 2 Effects of Countermeasures

Verification of each specification and selection of the best one were conducted by L_{27} orthogonal test based on the design of experiments. In the test, salt water was sprayed onto the seal which was pressed into a jig equivalent to the bearing and the test was conducted until water intruded into the bearing.

The test method is shown in **Fig. 3**.

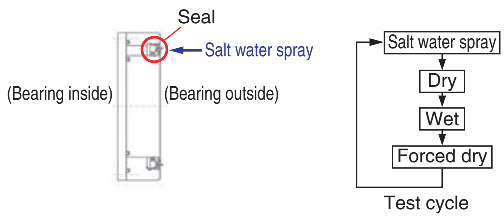

Fig. 3 Test method

Figure 4 shows the appearance of the fitting portion of the seal outside diameter after the test.

As seen in cases of water intrusion into seals in the field, water intruded through the rubber portion of seal outside diameter, corroded the metal fitting portion and finally intruded into the bearing.

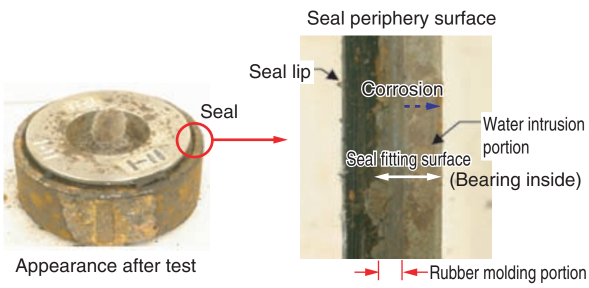

Fig. 4 Example of seal outside-diameter fitting portion after test

An analysis of variance was conducted to verify the effect of each specification condition based on the test results. As a result, it was revealed that the fitting length and the fitting interference of seal periphery rubber greatly correlate with muddy-water resistance. Results of the variance analysis are shown in **Table 2** and the number of test cycles until water intrusion in **Fig. 5**.

Table 2 Results of variance analysis (combined corrosion test result)

Factor	Sum of squared deviation	Degree of freedom	Unbiased variance	Variance ratio	P value	Contribution ratio	Determination
A : Fitting interference of seal periphery rubber	269.6	2	134.8	110.3	0	18.4	* *
B : Fitting length of seal periphery rubber	548.7	2	274.3	224.5	0	37.6	* *
C : Seal fitting surface roughness of outer ring	96	1	96	78.6	0	6.5	* *
D : Seal fitting surface roundness of outer ring	66.7	1	66.7	54.6	0	4.5	* *
E : Fitting interference of periphery rubber × fitting length of periphery rubber	198.4	4	49.6	40.6	0	13.3	* *
Error	19.6	16	1.2			19.7	
Total	1 198.9	26				100.0	

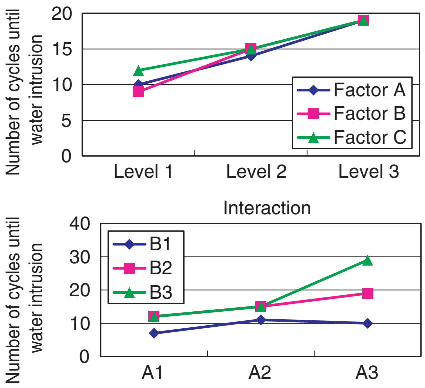

Fig. 5 Number of test cycles until water intrusion

As a result, the seal characteristic values showed larger in accordance with larger fitting interference, larger fitting length of seal periphery rubber and smaller fitting surface roughness of outer ring. Better muddy-water resistance performance was obtained in accordance with larger fitting interference and larger fitting length of seal periphery rubber.

Figure 6 shows the comparative test results of muddy-water resistance performance between the seal with optimal specifications in which the paradoxical effect due to increased fitting interference and fitting length of seal periphery rubber is taken into account and the seal with current specifications.

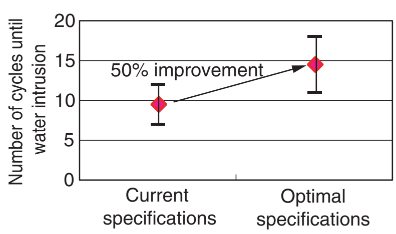

Fig. 6 Comparative test results of muddy-water resistance performance between optimal specifications and current design

Sealing performance of the seal with the optimal specifications showed 50% improvement compared with that with current specifications and the target was achieved.

3. Low-Temperature Seal

In Russia, the number of annual automobile sales had been increasing year by year through 2008[1]. However road conditions are still bad and, in certain regions, temperature reaches – 40℃ or below. It is important for seals to be able to maintain sealing performance even under such extremely cold environments (like in Russia, Alaska, Canada, etc.). Research and development of JTEKT started with material tuning and ended up with verification of effects with the aim of achieving five times better sealing performance than the current level under low-temperature conditions.

3. 1 Causes for Water Intrusion

There are various causes for water intrusion into bearings such as an axle structure severely exposed to water, a defect in seal production process, improper mounting of seal or deterioration due to long time service. Bearings used in Russia often showed typically a lot of mud adhered on the bearings, which seemed to indicate that the bearings had been exposed to severe wet conditions.

Reviewing peripheral structure to lessen exposure conditions of bearings to water is sure to bring about much better sealing performance. At the same time, improvement in muddy-water resistance of seals will further enhance the bearing performance. Based on the investigation results of conditions in the Russian market and bearings used in Russia, we reasoned that the mechanism of water intrusion was as follows:

(1) Temperature goes down in winter.
(2) Seal rubber materials (nitrile rubber) harden and show embrittlement due to low temperatures.
(3) Seal lip reaction force lessens due to hardening and embrittlement.
(4) Seals are exposed to muddy salt water during running.
(5) Muddy salt water enters into bearings through seal lip portions.

As a result, we have assumed that seal rubber materials lose their elasticity in winter (at low temperatures) and cannot maintain the designed sealing performance.

3. 2 Characteristics of Rubber

Characteristic targets were set up as follows to improve the seal rubber materials so as not to show hardening or embrittlement even under low temperature conditions.

(1) Elasticity 10% recovery temperature (TR10)≦– 40℃

(2) Other physical properties (hardness, tensile strength, elongation and oil resistance) remain unchanged.

TR: Temperature-retraction

TR test: Test for evaluating low temperature performance by measuring the temperature at which an elongated and frozen test piece shows the predetermined shrinkage ratio by elasticity recovery in accordance with temperature rise (JIS K 6261).

TR diagram of the improved rubber material is shown in **Fig. 7**.

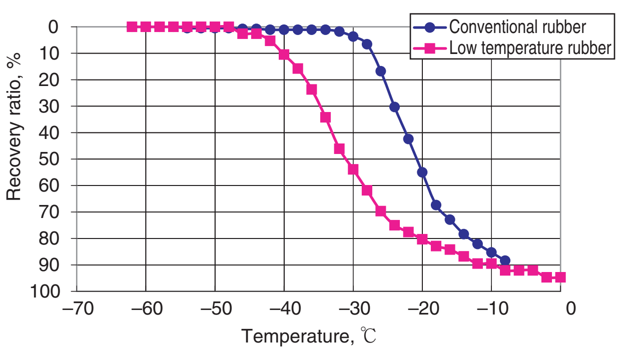

Fig. 7 TR diagram

3. 3 Results of Evaluation

A durability test of the seal alone was conducted. Test results are hereunder shown. **Figure 8** shows the cross section of the test seal.

Seal dimensions: ϕ63mm × ϕ76.9mm × 4.9mm

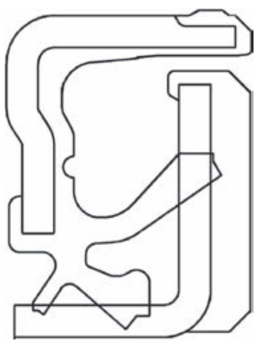

Fig. 8 Cross section of test seal

Test conditions are shown in **Table 3** and test results in **Fig. 9**.

Table 3 Conditions for low-temperature muddy saltwater durability

Test	Test of seal alone
Rotational speed	0 ⇔ 500 min^{-1}
Temperature	-20℃
Sealing matters	Kanto loam powder, NaCl, Water (Ratio in mass 1 : 2 : 7)
Amount of salt water	Salt water filled up to shaft center level

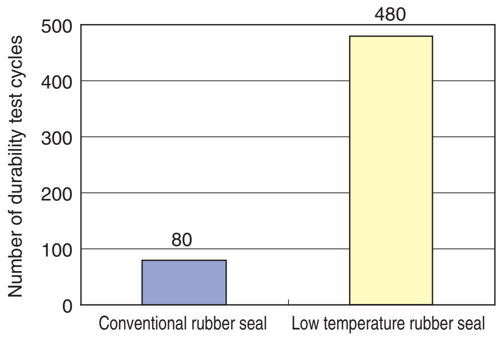

Fig. 9 Results of low-temperature muddy salt water durability test

The low temperature rubber seal achieved five times better durability than the conventional rubber seal thanks to the effect of improvement in the rubber elasticity recovery ratio at a temperature of – 20℃.

At normal temperature, the muddy-water resistance was proven to be the same as the seal with the conventional rubber material.

There was fear of a strength decrease or change of friction torque at higher temperatures. However, in the JTEKT standard test, it has been proven that the rubber material showed equivalent performance when compared to the conventional one.

4. Development of Super Low-Torque Seal

As a measure to strengthen the global warming protection, CO_2 emissions of new vehicles will be regulated to 120 g/km or less from 2012 in Europe and the US CAFE energy-consumption regulations will be tightened year by year until 2020. Improvement in fuel efficiency is becoming an issue of urgent need in the world automotive market[2].

JTEKT has been engaged in lowering the torque of hub units to improve automobile fuel efficiency.

Figure 10 shows how much each factor correlates with torque of a hub unit[3], and as seen from the result, seals have great influence on it. It is therefore effective to lessen the friction torque of seals for lowering the torque of hub units.

JTEKT has been making an effort to lower the torque of hub unit seals and already succeeded in developing seals for hub units with 40% less torque, which are now in serial production. At this time, a super low-torque seal with further improved muddy-water resistance has been developed.

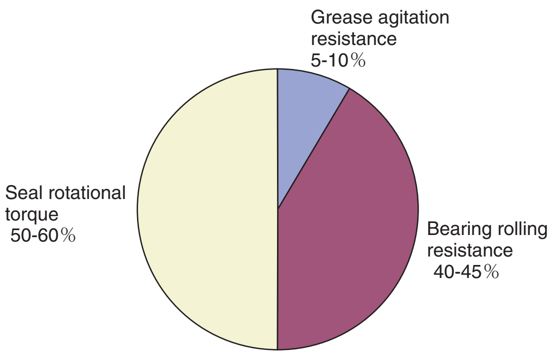

Fig. 10 Torque contribution ratio of each factor in hub unit

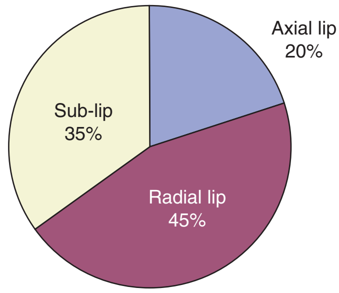

Fig. 11 Contact load ratio

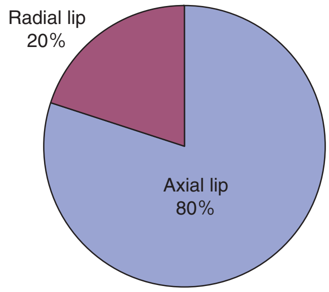

Fig. 12 Contribution ratio of muddy-water resistance

4. 1 Target Performance

Since there is growing market demand to achieve lower friction torque and to reduce problems with water intrusion which is a main cause of wheel bearing troubles in the market, the following targets were established:

- Torque reduction: 70% (as compared with the conventional seals, or 50% reduction as compared with the low-torque seals)
- Muddy-water resistance: 50% improvement

4. 2 Seal Structure

Figures 11 and **12** show how much each seal lip correlates with the contact load (torque) and muddy-water resistance. Based on this data, it has been decided that both torque reduction and muddy-water resistance improvement should be attained by structural improvement or abolition of the radial lip which has large influence on the torque and, at the same time, addition of an axial lip which has a large contribution to muddy-water resistance.

Figure 13 shows the structure of a conventional sealing arrangement for a hub unit. Reduction of contact load by optimizing the design of each lip alone has not been sufficient for further lowering the torque of the low-torque seals already developed and attaining the target level of the super low-torque seal. Therefore, the seal structure has been reviewed.

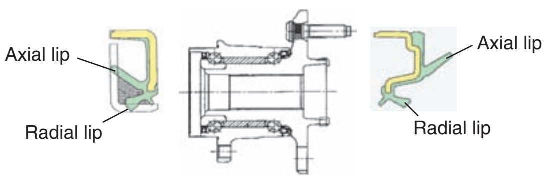

Fig. 13 Conventional seal structure of hub unit

Figure 14 shows the structure of the new seal. The reduction of the torque has been achieved by abolishing the radial lip which has large sliding resistance and adopting the double axial lips which are superior in followability.

With regard to a PACK seal (an inboard hub unit seal), the target level for torque reduction has also been attained by improving the roughness of slinger surface which can retain grease on the slinger surface and optimize the oil film between the lip and the slinger.

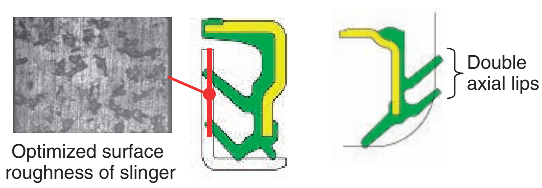

Fig. 14 Super low-torque seal structure

4. 3 Evaluation Results

4. 3 .1 Rotational Torque

Figure 15 shows the results of rotational torque measured under the test conditions shown in **Table 4**. From this result, it has been confirmed that the target level of 70% torque reduction has been achieved.

Table 4 Test conditions

Rotational speed	1 000 min^{-1}
Torque	Until torque stabilization
Lubrication	Grease lubrication
Temperature	Natural rise of temperature
Shaft eccentricity	None

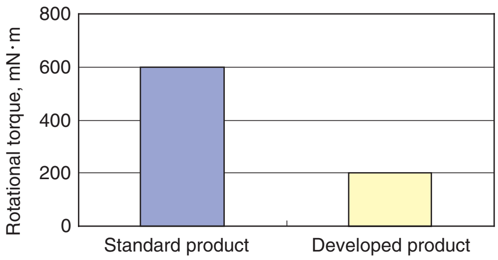

Fig. 15 Seal torque measurement results

4. 3 .2 Muddy-Water Resistance Test

Figure 17 shows comparative test results of muddy-water resistance under the test conditions shown in **Fig. 16** and **Table 5**. Muddy-water resistance has been improved to reach a two times better level than the target of 50% reduction.

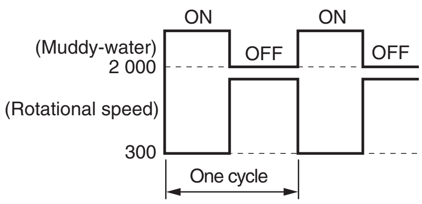

Fig. 16 JTEKT standard test conditions

Table 5 Test conditions

Rotational speed	300 ⇔ 2 000 min^{-1}
Temperature	Natural rise of temperature
Amount of muddy water	Up to shaft center level

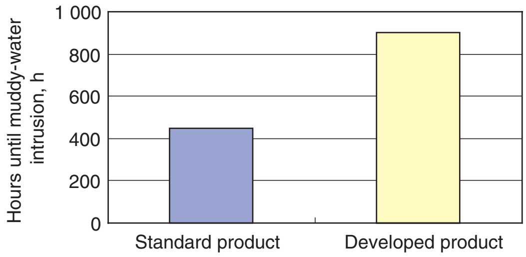

Fig. 17 Muddy-water resistance test results

5. Conclusion

This report introduces new wheel bearing seal technologies; the improvement of muddy-water resistance, the low temperature performance seal, and the super low friction torque seal.

In order to continue to provide such wheel bearing seals that meet demands from the world automobile manufacturers, we will promote the development of seal products which are capable of showing high performance including high sealing efficiency and low torque in a wide range of regions, resulting in contributing to the world and, at the same time, establishing the JTEKT design standards.

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