Development of Ball Bearing with Integrated High Oil Pressure Resistance Seal

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Four-stroke engines have been widely used in motorcycles and special vehicles in order to meet emission control regulations and improve fuel efficiency. Lubricating oil is fed by an oil pump to the four-stroke engine, and a ball bearing with integrated oil pressure resistance seal is used at the oil pathway of the shaft end as an oil pressure bulkhead. As a result of improvements in engine performance, demands for higher speeds, higher pressures and improved sealing performance have increased. To meet these demands, we have developed a ball bearing with integrated high oil pressure resistance seal. This report describes this development.

***Key Words**: Ball bearing, pressure resistance seal, four-stroke engine, environment, lip reaction force*

1. Introduction

The worsening global environment has, in recent years, been crying for immediate countermeasures. In order to comply with regulations concerning fuel efficiency and emission control for four-wheel automobiles, many latest technologies have been deployed.

When it comes to motorcycles, two-stroke engines using mixed gasoline have kept losing their ground on new models because of their structural difficulty to adequately control the mixed gasoline in coping with those environmental and fuel economy regulations, whereas four-stroke engines, with their easiness to control fuel efficiency and emission, have made inroads therein. This situation is shown in **Fig. 1**, which depicts yearly shares of new motorcycles models produced by Japanese manufacturers accounting for the two-stroke engines and the four-stroke engines[1]. As shown in **Fig. 2**, the four-stroke engines are equipped with a route for efficient forced circulation of the oil from an oil pump to each location. This oil does not only lubricate each location, but also plays the roles of cooling the engine pistons and other locations heated by sliding as well as carrying away foreign materials. It is common to pass the pressurized oil through the hollow holes of the crank shaft, main shaft and counter shafts of transmission. Sealed bearings at the shaft ends are used as the oil barrier. For such applications, ball bearings with integrated high oil pressure resistance seals (hereinafter referred to as pressure resistance seal bearings) have been successfully offered to meet such requirements for high pressure resistance. The demands for these bearings have been increasing with the spread of four-stroke engines. Now, in addition to the requirement for high pressure resistance, other performance requirements such as reduced friction for better fuel economy, have also been increasing.

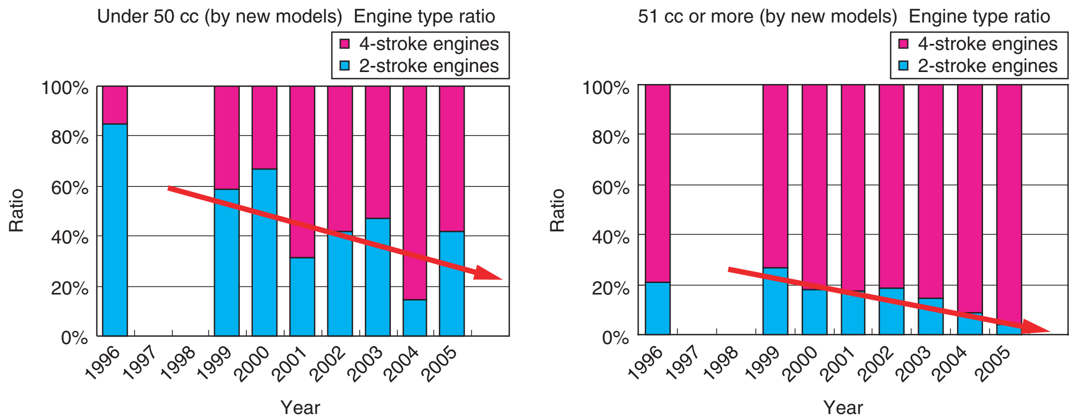


Fig. 1 Ratio of engine types used in new models by Japanese motorcycle makers[1]

This report presents the JTEKT's lineup of the pressure-resistance ball bearings as well as ongoing development of pressure-resistance seal bearing.

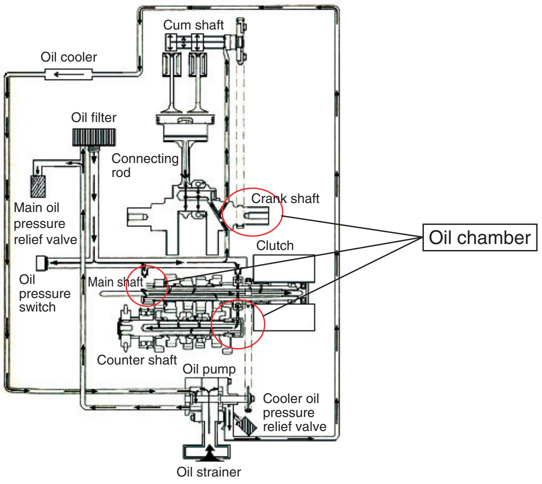


Fig. 2 Schematic drawing of oil circulation for four-stroke engine

2. Operating Environment of Pressure Resistance Seal Bearings

2. 1 Roles of Oil

The oil supplied by oil pump in the four-stroke engine has the roles described above. The oil that has been circulated through various locations comes back to the oil pan from which it is sucked up by the oil pump through the oil strainer. Then the oil is supplied through the oil filter to each route, as well as through the oil chamber to the lower part of the piston, the valve gear system, the gear inner position and the rotation supporting locations. The pressure resistance seal bearing is used at the end of the rotating shaft, also serving as the oil barrier. This bearing containing high oil pressure seal has been developed to replace the former combination of a rolling bearing and a shaft seal or washer for allowing larger space in the engine as well as easier installation.

2. 2 Required Performance of Pressure Resistance Seal Bearing

The pressure-resistance seal bearings are required to have the following performance:

(1) Enhanced sealing capability

Elimination of oil leakage in the oil circulating route ensures sufficient oil pressure level and oil supply to the extreme ends, and helps improve efficiency of the oil pump.

(2) Reduction of friction

In case a large displacement single cylinder engine is used in ATV (4-wheel buggy), for instance, there is concern over increased friction and decline of fuel efficiency because of increased seal sliding diameter due to larger crank journal bearing diameter. To alleviate such concern, reduced friction is instrumental.

(3) Improved oil pressure resistance

Inadequate action of the relief valve in a condition of high kinetic viscosity of oil in start up at low temperature leads to high oil pressure, but a bearing should be available without trouble even under high oil pressure.

3. Lineup of Pressure Resistance Seal Bearings

JTEKT's lineup of pressure resistance seal bearings is summarized in **Table 1**, and features of each type are described below[2]:

3. 1 RUE Type

The RUE type is the most commonly used for applications under medium oil pressure. It has built up a long list of successful applications.

The seal lip design features a thick elastomer to prevent the lip from being turned over by the oil pressure because the lip is pressed against the sliding surface. Also, the lip is provided with radial ribs that help retain small amounts of oil at the sliding position of the lip, even under heavy pressure by forcing the lip against the sliding surface, so that wear on the lip can be alleviated.

Originally the OD portion of the seal (seal head part) was a curled metal sheet that was caulked into the outer ring counter bore. This fitting was tight enough to overcome the rotating force given by the increased friction at the seal lip under oil pressure.

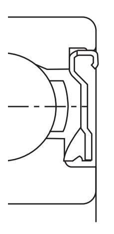
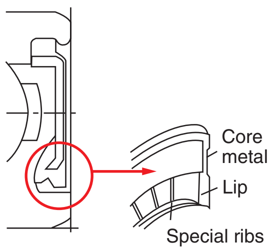
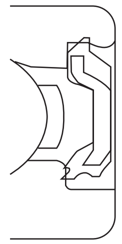
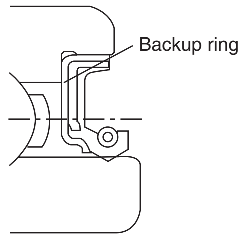
However, the curled design of the seal head part made it difficult to increase the metal thickness, while the seal performance deteriorated under higher oil pressure due to deformation of the core metal. Therefore, the newly developed seal type, RUE, incorporates elastomer seal head (in place of the curled design metal with limited stiffness) designed to ensure a tight fit, thereby allowing the core metal to be as thick as possible in order to withstand high oil pressure without deformation.

Currently the elastomer seal head type with high reliability is recommended.

3. 2 RC5 Type

The double lipped seal design of the RC5 type is intended for applications that involve high speed, but not high oil pressure. Due to the double lipped design the seal can avoid extreme increases in the lip contact width under oil pressure. Also because of the oil reservoir provided between the lips, the seal can supply the appropriate amount of lubricant to the sliding surface resulting in a reduction of biased wear on the lip as well as temperature rise at high speed.

Table 1 Lineup of high-pressure resistance seal bearings[2)]

Type	RUE type		RC5 type		RO type	
Seal head design	Curled type	Elastomer fitting type				
Design						
Seal lip peripheral speed, m/s	For low speed	Max. 11	For high speed	Max. 20	For medium speed	Max. 15
Pressure resistance, MPa	For medium pressure	Max. 0.5 (Normally 0.3)	For low pressure	Max. 0.2 (Normally 0.1)	For high pressure	Max. 0.7 (Normally 0.5)
Features	Alleviation of lip wear by supplying small amount of oil on the lip sliding surface		Double lip design minimizes expansion of contact width. The oil reservoir provided between the lips alleviates lip wear.		Backup ring provided to the lip backside restrains the lip deformation and alleviates lip wear	
Lip type	Axial		Axial		Shaft seal	
Material	Acrylic or fluoro rubber		Acrylic or fluoro rubber		Fluoro rubber	

3. 3 RO Type

In order to cope with high oil pressure, the RO type is a bearing with integrated shaft seal type that has recorded performance as a pressure resistant shaft seal. So that biased wear of seal can be minimized, the seal lip elastomer thickness is increased to restrain seal lip deformation and a backup ring is provided.

Figure 3 shows the relationship of the seal lip peripheral speed and the pressure resistance of the above seal types.

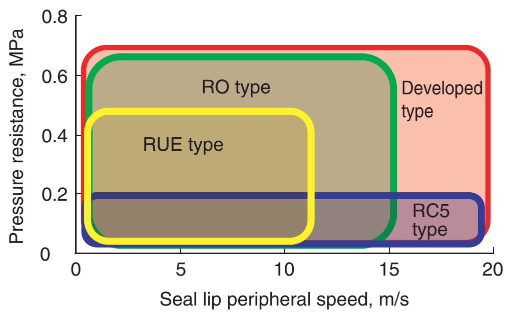


Fig. 3 Seal design range of application

4. Development of Ball Bearing with Integrated Pressure Resistance Seal

In recent years, the change in the operating environment of the bearing has dictated the bearing seal to be upgraded in high-speed, high pressure and high sealing capability with reduced friction. Therefore, we have set the criteria of seal optimization to satisfy these requirements compared to the current design. The development targets are listed in **Table 2**.

Table 2 Target of development

Item	Target value	Remarks
High pressure resistance, MPa (Test time, h)	0.7 (100)	No remarkable oil leakage after test
Sealing capability, cm^3/min	Oil leakage 0.1 or less	–
Seal peripheral speed, m/s	20	–
Reduction of friction	30% of current level	–

4. 1 Failure Mode of RUE Type Seal

RUE type seal samples were subjected to operating conditions exceeding the design operating range shown in **Fig. 3** with the resultant failure modes as shown in **Fig. 4**. The factor analysis based on these results is shown in **Fig. 5**. The failures of RUE seals include oil leakage and interference with other parts, which are all traced back to deformation of the core metal, excessive seal lip interference and too rough seal sliding groove. Also, excessive friction is mainly caused by excessive seal lip interference.

In an effort to work out a seal design which can handle operating conditions exceeding the current operating range, we have promoted development while taking these factors into consideration.

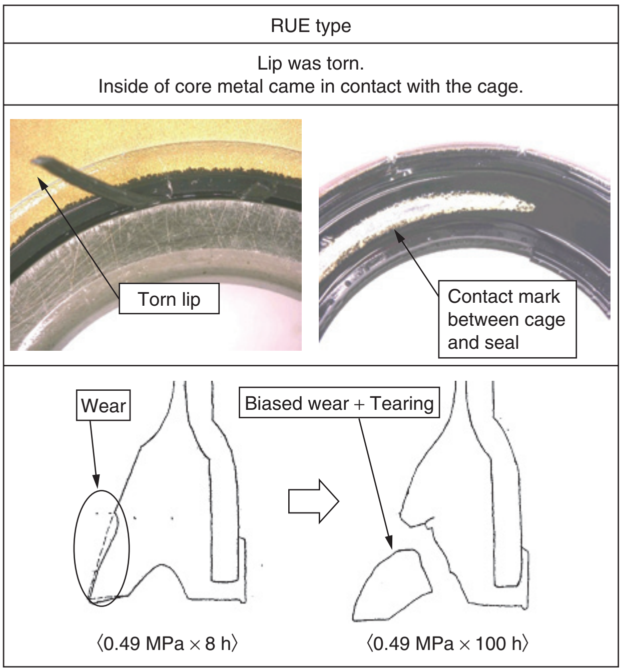


Fig. 4 Failure mode of RUE type seal under excess oil pressure

4. 2 Features of Developed Product

Figure 6 shows schematic diagram of the developed bearing, and its features are described below:

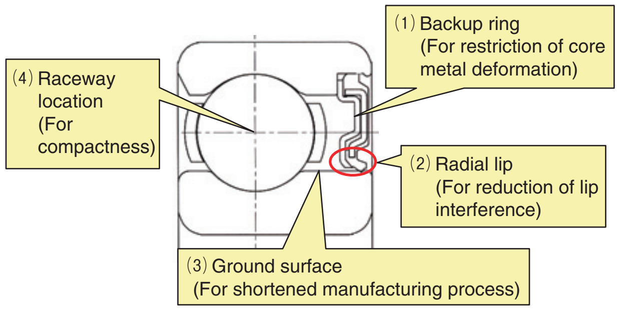


Fig. 6 Developed part outline and features

(1) Restraint of core metal deformation:

The back up ring provided inside the seal is effective to restrain deformation of the core metal due to oil pressure load.

Furthermore, this design of combining two core metals whose thickness is nearly the same as that in the current (RUE type) seal facilitates forming process to improve stiffness.

(2) Reduction of interference of radial lip:

The radial lip design is elected because its seal lip interference is less affected by deformation of the core metal due to oil pressure.

Also, provision of backup ring close to the seal lip is designed to prevent seal lip deformation under high pressure.

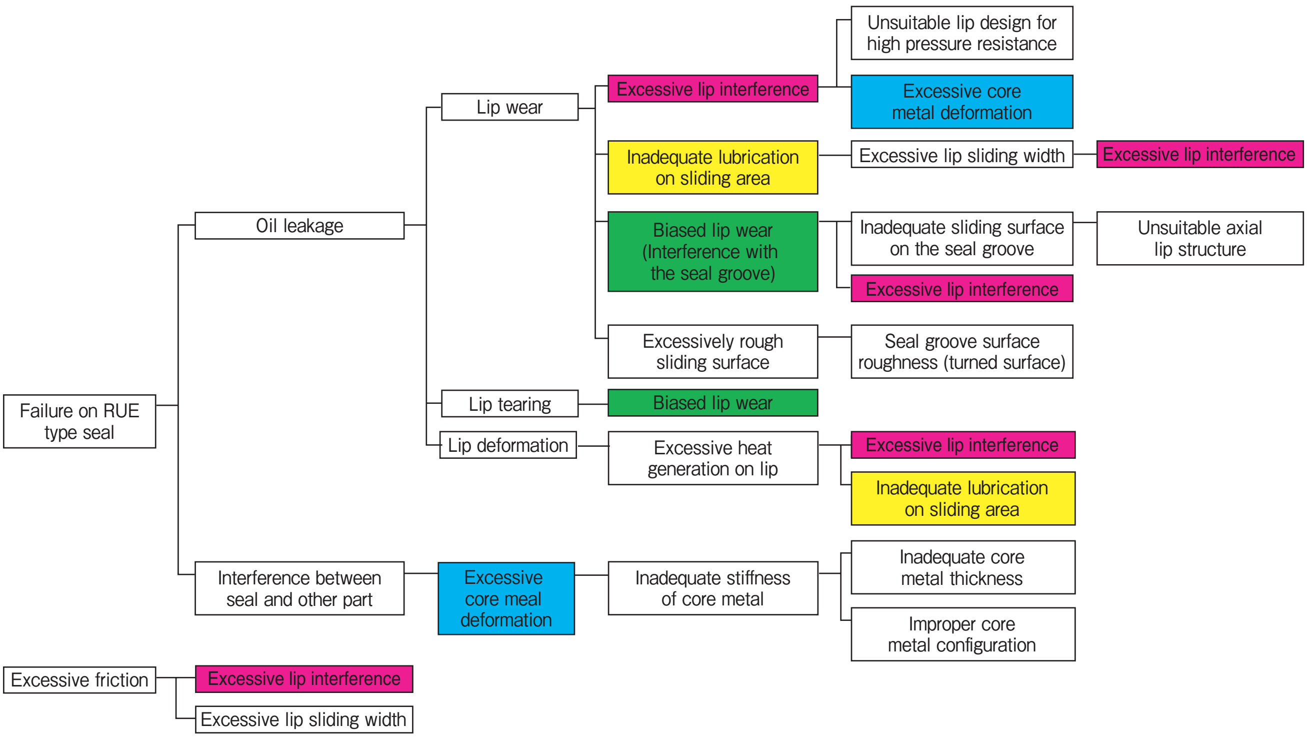


Fig. 5 Factor analysis of failure and large friction for RUE type seal

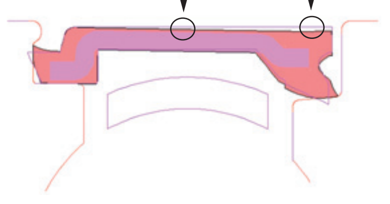
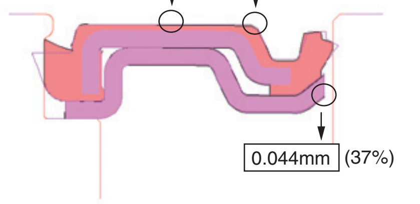
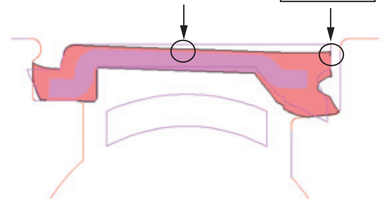
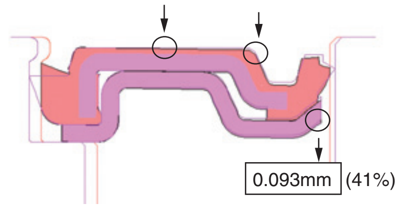
Seal type		RUE type	Developed seal
0.5 MPa	Core metal axial displacement		
	Lip reaction force	147 N	52 N (35%)
1.0 MPa	Core metal axial displacement		
	Lip reaction force	340 N	86 N (25%)

Fig. 7 Results of FEM analysis

(3) Saving of manufacturing process:

As the seal has a radial lip design, the seal groove processing is not required, while the inner ring land can be ground easily to control the roughness of sliding surface.

(4) Compact Bearing Design

In order to accommodate the seal in the standard bearing dimension, the raceway axial position is offset for compactness.

4. 3 Verification of Effects of Developed Product

4. 3. 1 Deformation of Core Metal and Lip Reaction Force

A comparative FEM analysis was conducted on the core metal deformation and the lip reaction force of RUE type seal and the developed product under high oil pressure with the results as shown in **Figs. 7** and **8**. From these results, it is estimated that the axial displacement of the core metal and lip reaction force can be reduced to 40% and 30% respectively, and thereby, the lip wear, lip deformation and friction can be alleviated significantly.

4. 3. 2 Starting Torque (Friction)

The "relationship between the oil pressure and the bearing starting torque" for the developed seal and RUE type seal are summarized in **Fig. 9** in terms of experimental measurements and the calculated values based on the FEM analysis. The results verified that the developed seal has succeeded in reducing the starting torque to approximately one third compared to the RUE type. It is also noted that the experimental values were almost completely consistent with the computed values based on the FEM analysis. It is, therefore, considered feasible to predict performance of a seal based on FEM analysis of lip reaction force and core metal deformation.

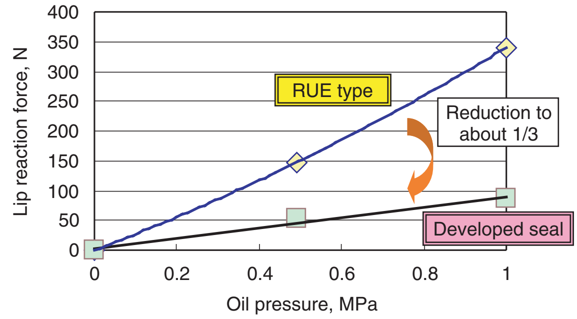


Fig. 8 Relationship between oil pressure and lip reaction force

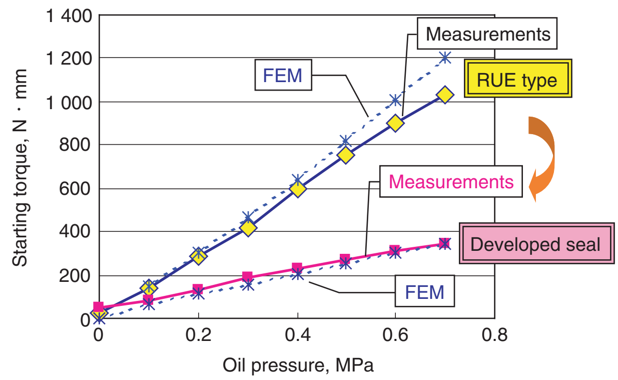


Fig. 9 Relationship between oil pressure and bearing starting torque

4. 3. 3 Durability Test

A durability test was conducted under the test conditions shown in **Table 3**. The test results, as shown in **Figs. 10** and **11**, verified that both the lip wear and the oil leakage were within the criteria even after 100 hours.

Table 3 Test conditions

Developed seal	
Oil pressure, MPa	0.7
Rotational speed, min^{-1}	7 000
Time, h	100
Oil temperature, ℃	140

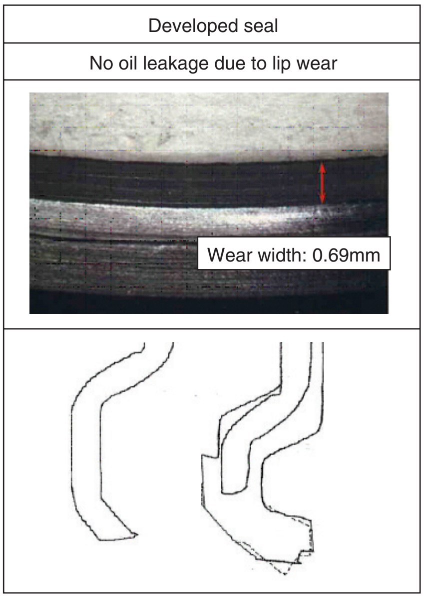


Fig. 10 Cross-sectional form (after test)

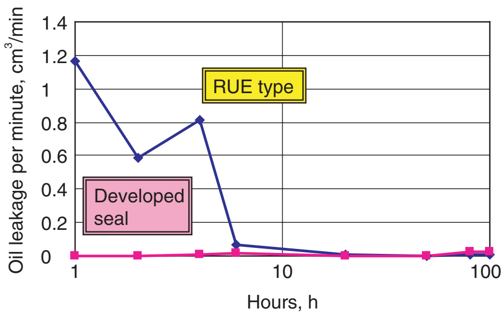


Fig. 11 Amount of oil leakage per minute (after test)

5. Conclusions

(1) A lineup of pressure-resistance seal bearings applicable in all conditions ranging from low to high pressures and from low to high speeds has been completed.

(2) A seal which incorporates countermeasures to prevent core metal from being deformed as well as to minimize change of seal lip interference has successfully restrained lip wear, withstood high speed and high pressure and has been developed.

(3) Starting torque of the bearing with the developed seal was approximately one third of the RUE type sealed bearing, vindicating that it is effective to reduce friction.

Thus, it has been confirmed that the developed product can meet the requirement of four-stroke engines for higher performance.

Finally, we would like to express our thanks to Uchiyama Manufacturing Corp. for their cooperation in this development of pressure resistance seal bearing.

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