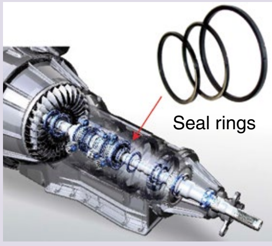
Verification of Torque Reduction for Low Torque Seal Ring by Fluid Analysis

Takuya ISHII*
Tomohiko OBATA**



In order to achieve demands of fuel consumption standard, seal rings for automotive transmission are required to further reduce torque and oil leak. **NTN** developed “Low Torque Seal Ring” and started mass production. It has V-shaped lubrication grooves, which reduces torque by 60% in comparison with conventional products. This article introduces fluid analysis results of torque reduction by V-shaped lubrication grooves in “Low Torque Seal Ring”.

1. Introduction

Multiple seal rings made of resin with outer diameters ranging from 15-60 mm are used in vehicle transmissions (AT, CVT, etc.). These seal rings are required to have low torque and low oil leakage properties to achieve low fuel consumption of vehicles. In order to respond to this requirement, **NTN** developed “Low Torque Seal Ring”[1), 2)] made of polyether ether ketone (PEEK) resin with a V-shaped lubrication groove and started volume production **(Fig. 1)**.

The number and shape of the V-shaped lubrication grooves was optimized by fluid analysis and experiments to further reduce torque of the low torque seal ring. This article introduces the verification result of the fluid analysis regarding the reduction of torque for the low torque seal ring.

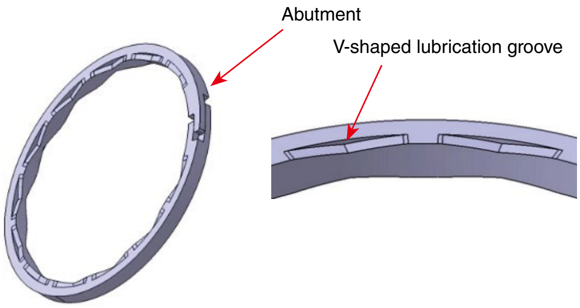


Fig. 1 Low torque seal ring

2. Role and Operation of the Seal Ring

Oil is sealed by the seal ring that slides on the moving components. Seal rings are installed between the shaft and housing that moves in relative motion within the oil hydraulic circuits of transmissions. They are pushed to both the inner surface of the housing and the side wall of the shaft groove by oil hydraulics sealing oil and maintaining the pressure inside the oil hydraulic circuit, as they slide.

The required performance of the seal rings is low torque, low oil leakage and high wear resistance. When torque is reduced, transmission efficiency increases achieving higher energy efficiency. Reduced oil leakage leads to a more efficient and smaller oil-hydraulic pump which results in higher energy efficiency. To maintain low torque and low oil leakage operation and realize long operating life, seal rings are required to be wear resistant and at the same time prevent wear of the mating component which the seal rings slide on.

Fig. 2 shows the operation of **NTN**’s conventional product which has a rectangular cross section. Since the contact area of the seal ring and the side wall of the shaft groove is smaller than the contact area of the seal ring and the inner surface of the housing, the seal ring slides on the side wall of the shaft groove. It is this side wall of the shaft groove that has lower sliding resistance when the shaft or the housing rotates. Oil leakage is small as the seal ring has area contact with the side wall of the shaft groove.

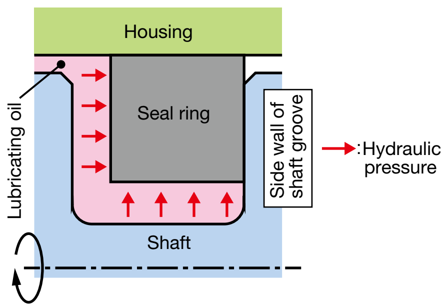


Fig. 2 Operation of seal ring

* Precision Plastics Engineering Dept., Composite Material Product Division
** Advanced Technology R&D Center

3. Low Torque Seal Ring

3.1 Features

The Low Torque Seal Ring realized low torque and low oil leakage by installing a V-shaped lubrication groove on the surface of the seal ring which slides on the side wall of the shaft groove. It uses BEAREE PK5301, which is a material made of PEEK resin with special additives. It has V-shaped lubrication grooves on the side formed by injection molding and the abutment is made of complex shape. Oil leakage from the abutment is reduced, by making it a complex shape.

The Low Torque Seal Ring has the following features compared with **NTN**'s conventional product.

(Features)

(1) Reduction of torque by up to 60%

(2) 1/10 the wear rate

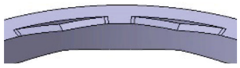
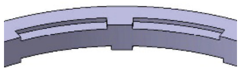
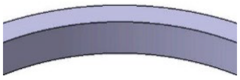
(3) Equivalent low oil leakage property

3.2 Comparison of the Lubrication Groove Shapes

3.2.1 Torque Measurement Results

Table 1 shows a comparison of torque using 3 types of seal rings with different shapes of lubrication grooves and without grooves. **Fig. 3** shows an outline of the test equipment. Torque was measured by circulating oil between two seal rings installed on the shaft grooves, applying oil pressure and rotating the housing.

Table 1 Seal rings under test

Seal rings under test	Shape of the lubrication grooves on the side
V-shaped lubrication grooves (12 on one side)	
Square-shaped lubrication grooves (12 on one side)	
No lubrication grooves	

Seal ring size: OD: 50 mm, thickness: 1.6 mm, width: 1.5 mm

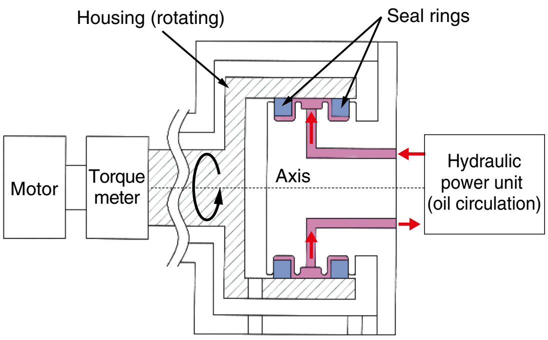


Fig. 3 Outline of test equipment

Fig. 4 shows the relation between the oil hydraulics and torque. The measured torque for two seal rings was divided by 2 to obtain torque for one seal ring. The seal ring with the V-shaped lubrication grooves showed lower torque than the seal ring without grooves (**NTN**'s conventional product) by 60-70% and the seal ring with square-shaped lubrication grooves by 20%.

[Test condition]
Oil hydraulics: 0.5-2 MPa,
rotation speed: 4,000 min^{-1}, ATF: 110°C
S45C Housing/shaft

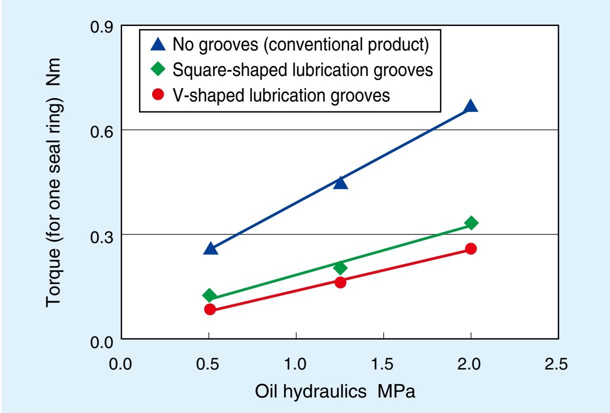


Fig. 4 Relationship between oil hydraulics and torque

3.2.2 Fluid Analysis Results

As the reason for lower torque, it is assumed that application of the V-shaped lubrication grooves which reduced the contact area between the seal ring and side wall of the shaft groove promoted lubrication of the sliding surface. The difference of torque between two different shapes of the grooves is attributed to the difference of lubricating conditions. This was verified by fluid analysis.

Fig. 5 shows the analysis result of the model extracting fluid region of one lubrication groove. With the V-shaped lubrication groove, oil film pressure at one end of the groove is high due to a hydrodynamic effect. This axial force due to oil film pressure is in the opposite direction from the force that the seal ring is pressed on the side wall of the shaft groove by oil hydraulics; therefore, it reduced the latter force. It is also assumed that oil flowed from the end of the lubrication groove onto the sliding surface between the lubrication grooves due to difference of pressure helped reduce torque. On the other hand, the high pressure observed in the V-shaped lubrication groove is not observed in the square-shaped lubrication groove.

[Analysis condition]
Oil film thickness: 5 μm, oil hydraulics: 2 MPa, rotation speed: 4,000 min^{-1}, ATF(20°C)

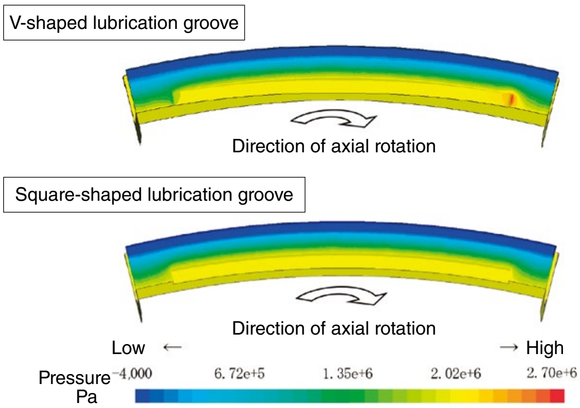


Fig. 5 Oil film pressure distribution on sliding surface

4. Verification of Torque Reduction by Optimization of V-Shaped Lubrication Grooves

4.1 Fluid Analysis Condition

The torque measurement result and oil film pressure distribution on the sliding surface revealed that the force appearing at the end of the V-shaped lubrication grooves is in the opposite direction from the force due to oil film pressure (oil film reaction force) which contributed to a reduction of torque. When the oil film reaction force is greater, the torque is lower. So, it is assumed that the greater the number of the V-shaped lubrication grooves and the wider the groove widths, the greater the oil film reaction force. Therefore, this was verified by the fluid analysis.

Fig. 6 shows the definition of the length, width, depth, angle of, and the distance between V-shaped lubrication grooves of the seal ring in the analysis. The size was set as: OD: 44 mm, thickness: 2 mm and width: 2.3 mm. The fluid region of one V-shaped lubrication groove of the seal ring was modeled with fluid analysis and the oil film pressure due to hydrodynamic effect was integrated to obtain the oil film reaction force of one groove. The product of this force and the number of grooves was defined as the oil film reaction force for one seal ring and a comparison of different conditions was made. Note that the oil film pressure at the contact area of the side of the seal ring and the side wall of the shaft groove was ignored, as this is very small compared to the V-shaped lubrication groove. In this analysis, the oil film thickness on the sliding surface was assumed to be constant at 5 μm, for ease of calculation, and the operating condition was defined as ATF pressure: 0.6 MPa, temperature: 20°C and rotation speed: 10,000 min^{-1}.

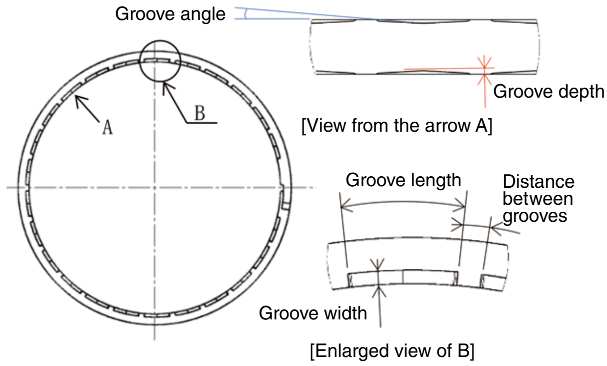


Fig. 6 Analysis of seal ring (24 grooves)

4.2 Fluid Analysis Results

4.2.1 Number of V-Shaped Lubrication Grooves

Oil film reaction force of one seal ring was obtained by fluid analysis for seal rings with 12 and 24 V-shaped lubrication grooves on one side. The distance between V-shaped lubrication grooves was the same and the length was changed between 12 and 24 grooves. The groove angle was also the same but the groove depths are different to allow for 12 or 24 grooves.

Fig. 7 shows the oil film reaction force of seal rings with 12 and 24 V-shaped lubrication grooves. As estimated, it was verified that the oil film reaction force is larger as the number of grooves is greater. Therefore, the greater the number of grooves, the better for reducing torque.

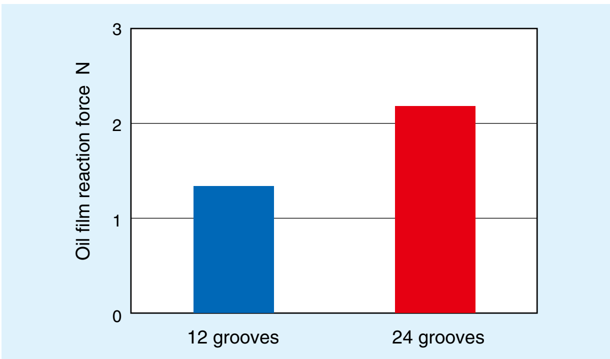


Fig. 7 Number of grooves and oil film reaction force

However, when the number of grooves increases, the number of the spaces between the grooves increases, too, which increases the contact area between the side of the seal ring and the side wall of the shaft groove, which result in higher torque. Therefore, there should be an optimum number of grooves for the minimum torque. To verify this, seal rings with a varying number of grooves were made and the torque measured. The seal ring size was: OD: 51 mm, thickness: 2.4 mm, width: 2.3 mm and the number of grooves: 12-30 on one side. The distance between grooves, groove width and groove angle were the same so the groove lengths and depths were different depending on the number of grooves. The measurement condition was: ATF pressure: 1 MPa, temperature: 80°C, rotation speed: 2,000 min^{-1}.

Fig. 8 shows the relation between the number of grooves and torque. Torque was reduced toward 24 grooves but increased at 30. The measurement results matched with the aforementioned concept, verifying that there is an optimum value for the number of grooves. Since the number of grooves is restricted by design and manufacturing reasons depending on the outer diameter, **NTN**'s Low Torque Seal Rings are lined up with the optimum number of V-shaped lubrication grooves by outer diameter.

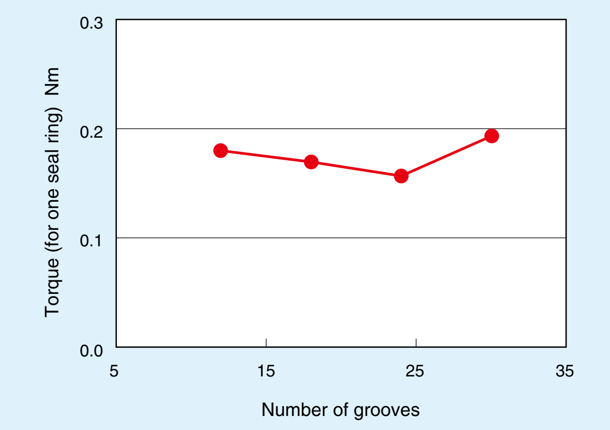


Fig. 8 Relationship between number of grooves and torque

4.2.2 Width of V-Shaped Lubrication Grooves

The oil film reaction force was obtained by fluid analysis for seal rings with V-shaped lubrication grooves with widths ranging from 0.2 to 0.7 mm. The number of grooves was 24 on one side and all the sizes are the same except for the groove width.

Fig. 9 shows the relation between the groove width and oil film reaction force. The verification result obtained matched with the estimate, as the groove width increased, the oil film reaction force increased. However, excessive groove width was found to cause increased oil leakage. Therefore, the groove width must be determined for each case, considering the size of housing and the shaft, eccentricity, wear amount of seal ring and housing, etc.

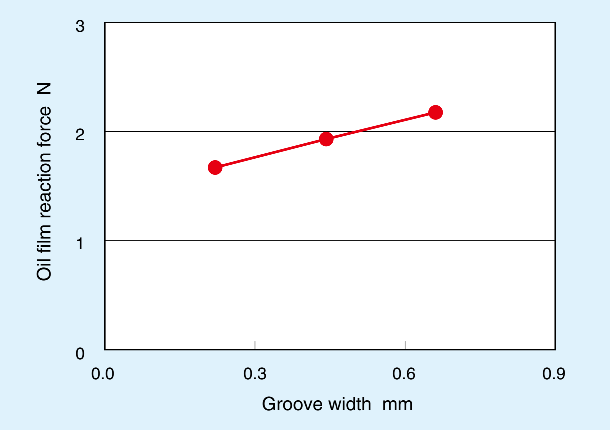


Fig. 9 Relationship between groove width and oil film reaction force

4.2.3 Angle of V-Shaped Lubrication Grooves

The oil film reaction force was obtained using fluid analysis, by increasing or decreasing the angle of the V-shaped lubrication grooves based on the seal ring with 24 grooves on one side described in 4.2.1. Since the distance between the grooves and the groove length and width were the same, only the groove depth is different based on the change of angles.

Fig. 10 shows the relation between the groove angle and oil film reaction force. The horizontal axis is a ratio of angle against the base angle. Within the range of this test, the oil film reaction force is almost the same regardless of the groove angles. Similarly, there is no impact to the groove depth. These results revealed that the number of grooves must be emphasized in the design of the V-shaped lubrication grooves, and the groove angle and depth do not need to be considered, if they are in the appropriate range.

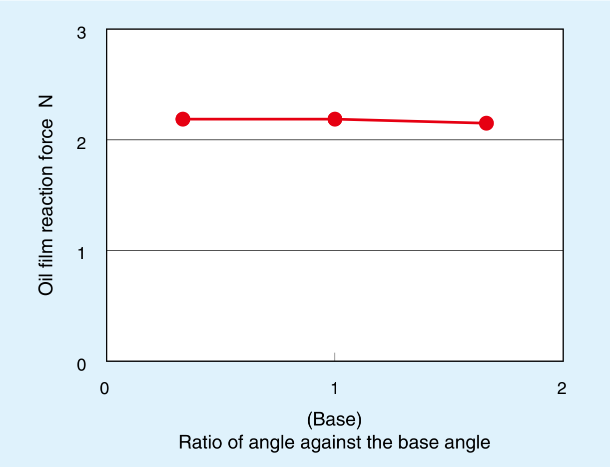


Fig. 10 Relationship between groove angle and oil film reaction force

4.3 Result of Torque Measurement with the Optimum V-Shaped Lubrication Grooves

The number and the shape of the V-shaped lubrication grooves are optimized based on the above fluid analysis. **Fig. 11** shows a comparison of torque from the seal ring with 12 V-shaped lubrication grooves discussed in Section 3.2 and the seal ring with the 24 optimized V-shaped lubrication grooves. The seal ring with 24 optimized grooves showed torque reduction of 10-15% compared to the seal ring with 12 grooves[3), 4)]. A seal ring that was of the following size was used for comparison: OD: 45 mm, thickness: 2 mm, width: 2.4 mm.

[Test condition]
Oil hydraulics: 0.4-1.2 MPa,
rotation speed: 2,000 min^{-1}, ATF: 80°C
Steel base housing/shaft

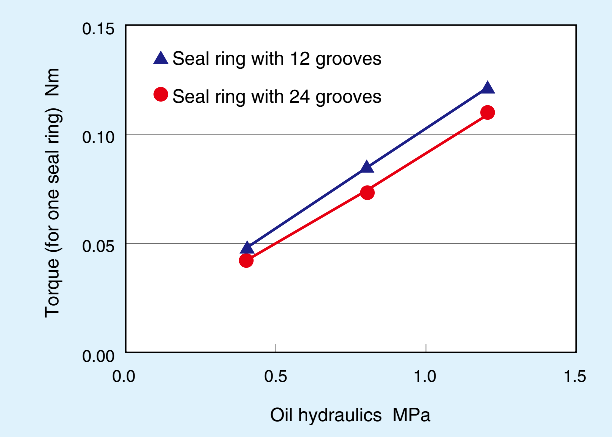


Fig. 11 Relationship between oil hydraulics and torque

5. Summary

This article introduced the verification result of the fluid analysis regarding reduction of torque of the Low Torque Seal Ring. The number and the shape of V-shaped lubrication grooves are optimized based on the fluid analysis and experiments to successfully reduce torque even further. Adoption of the Low Torque Seal Rings is well in progress as they could respond to the requirement of low fuel consumption of vehicles. We strive for further reduction of torque as we move forward.

Requirements for energy efficiency are increasing in many areas. We are poised to increase the speed of development for enhancing the performance of resin sliding components by adopting analytical approaches such as fluid analysis.

References

1) Kouzou Kakehi, Takumi Kondou, Takuya Ishii, Masato Yoshino: Development of Low Torque Seal Ring for Automotive Transmission, NTN TECHNICAL REVIEW No. 81 (2013) 68.
2) Takuya Ishii: Lower Torque of Seal Ring for Automotive Transmission, Journal of Society of Automotive Engineers of Japan Vol 71, No. 9 (2017) 81.
3) Takuya Ishii: Lower Torque of Seal Ring for Transmission, Automotive Technology Vol. 6, No. 1 (2018) 69.
4) Kayo Sakai, Tomonori Yamashita, Hajime Asada, Takuya Ishii: Proposal of Low Fuel Consumption and High Functionality of Composite Material Products for Automobile, NTN TECHNICAL REVIEW No. 85 (2017) 97.

Photo of authors

Takuya ISHII
Precision Plastics Engineering Dept.
Composite Material Product Division

Tomohiko OBATA
Advanced Technology R&D Center