Current Technology of Sealed-Clean Bearings for Transmissions

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ABSTRACT

The sealed-clean concept to extend rolling bearing life in contaminated lubricant conditions was introduced by the NSK group twenty years ago. Today NSK makes over 900,000 sealed-clean bearings per month, mostly for automotive transmissions. Now the concept has been advanced with improved seals and bearing material and a cylindrical roller bearing version is introduced.

1. Overview of Sealed-Clean Bearings

1.1 Principle of sealed-clean bearings

At the end of the 1970's, the Japanese automotive industry set out to create compact high-input torque transmissions to accept their newly improved engines. At that time, countermeasures to the emission control requirements had been completed and the clean high-performance engine would soon be introduced on the market. For low fuel consumption and to create space in the engine compartment, compactness and lightness of weight were also required. They asked the bearing industry to achieve longer bearing life in the new transmissions without increasing overall size.

NSK has made intensive studies of the failure mechanism in transmission bearings for many years. The fatigue status of a bearing can be analyzed by the measurement of retained austenite in the material structure and the full width half maximum (FWHM) value of X-rays diffracted at the raceway surfaces. These two measurements can be put together into the "fatigue index" to represent the fatigue condition of the bearing raceway steel.

Under clean lubrication conditions, the fatigue pattern shown in Fig. 1 is found. The peak of fatigue is at the same depth as the maximum shearing stress caused by rolling contact. According to the classic theory, a crack, the origin of flaking, occurs from a non-metallic inclusion at this depth. But the bearings used in actual vehicle transmissions show another pattern like Fig. 2. This latter type of fatigue has been called "surface fatigue" and the former classic mode is known as "subsurface fatigue". The surface fatigue is caused by poor lubrication conditions such as low viscosity of oil, water ingress, and oil contamination. The service life to the surface type of failure is very short compared to the onset of the sub-surface type. The greatest influence in transmission bearings is contaminant in the oil. The flaking process is shown in Fig. 3. The rolling elements roll over the dent made by contaminant crunching and high stress concentrations occur at the edge of the dent. Then a crack starts from the surface at the edge of the dent and leads to the release of a flake. We can see many dents in the surface of bearings which have been tested in actual

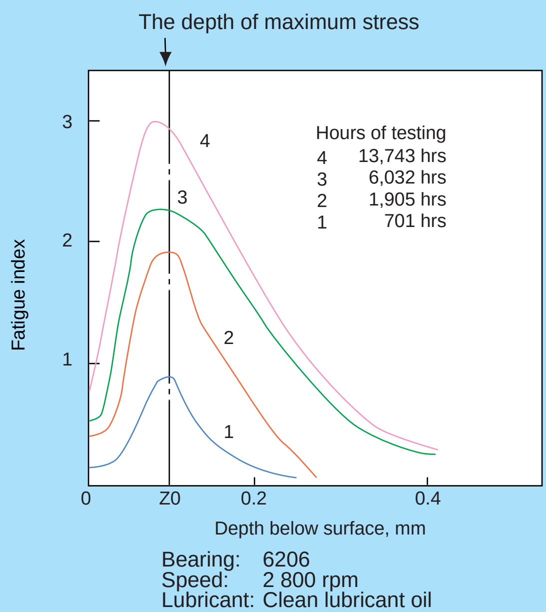


Fig. 1 Progress of fatigue of subsurface type

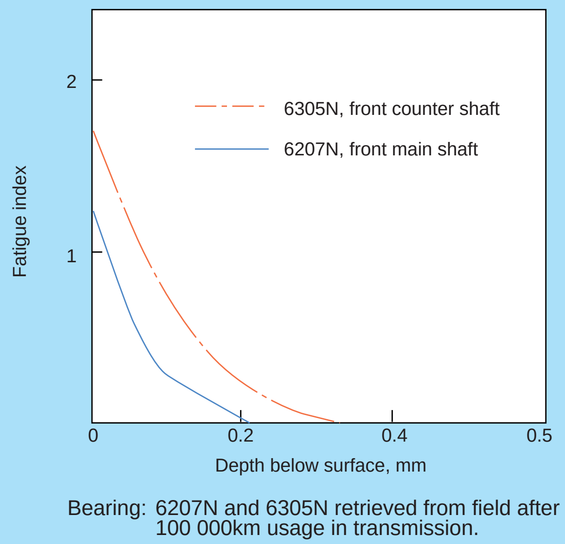


Fig. 2 Progress of fatigue of surface type

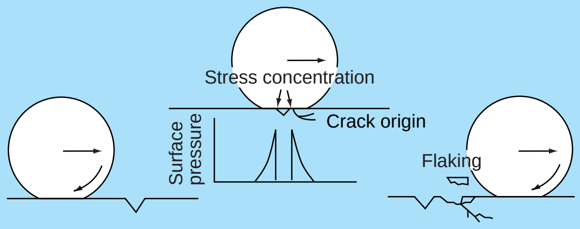


Fig. 3 Development of surface-originating flaking

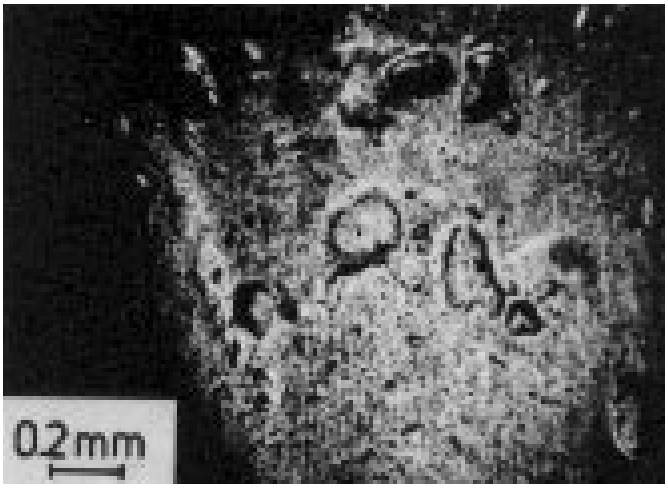


Fig. 4 Raceway of inner ring of ball bearing after 130 hours of test

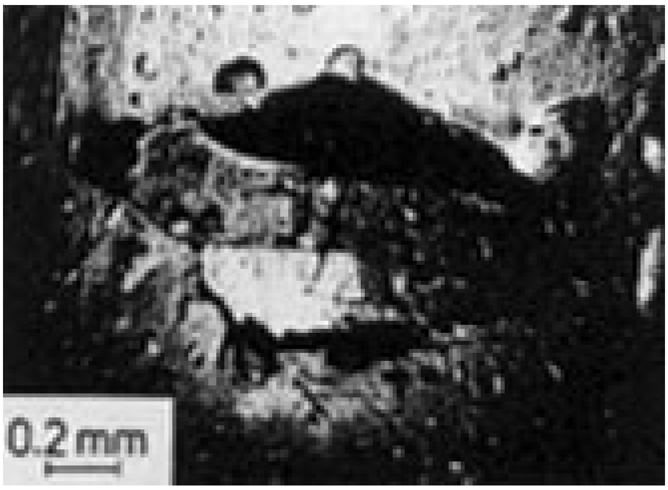


Fig. 5 Raceway of inner ring of ball bearing after 150 hours of test

transmissions. Fig. 4 and Fig. 5 show examples of such situations, which all represent potential sites for surface fatigue flakes.

The sealed-clean bearing has been developed to prevent contaminant ingress to the bearing interior. The sealed-clean bearing shown in Fig. 6 has a special design featuring a rubber seal which can accommodate the bi-directional axial movement of the inner ring caused by changing between drive and coast torque (UK Patent GB2071788, FP 2479374). This seal permits oil ingress to the bearing to ensure long term lubrication, but for initial lubrication a small amount of grease has been pre-packed, which is compatible with the transmission gear oil.

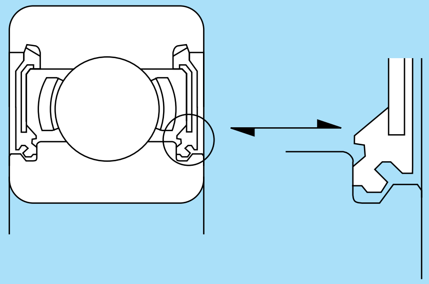


Fig. 6 Sealed-Clean bearing and its rubber seal on both sides

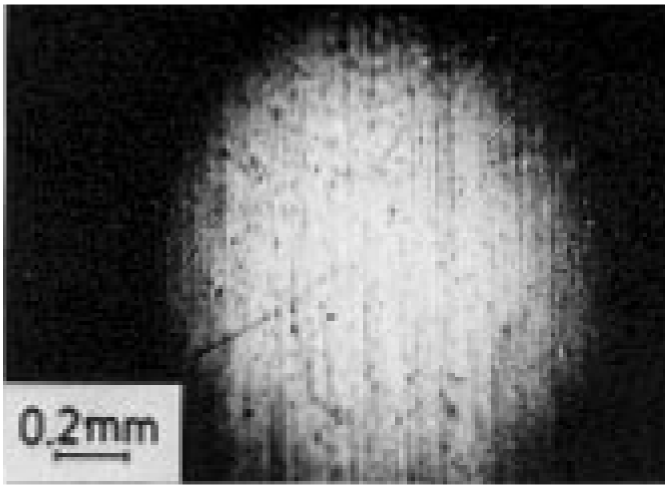
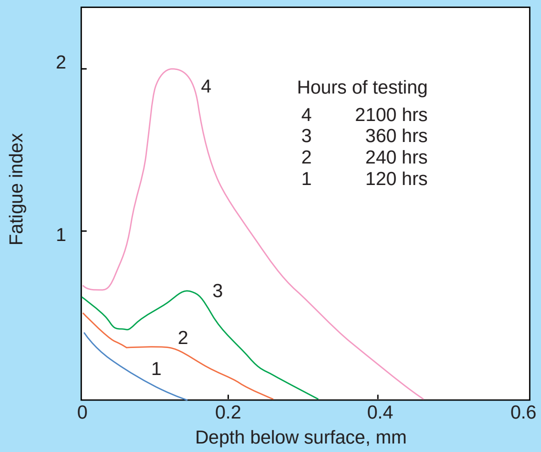


Fig. 7 Raceway of sealed-clean bearing after 500 hours of test

The raceway surface of a sealed-clean bearing is shown in Fig. 7. The surface is very clean even after long hours of testing, compared to the indented raceways of a standard bearing shown in Figs. 4 and 5. The fatigue analysis of the sealed-clean bearing is shown in Fig. 8. You can see the surface fatigue level is dramatically decreased compared to that of the standard bearing shown in Fig. 2. As a result, the sealed-clean bearing has a very long life in transmission applications.



Bearing: TM304 (ϕ20 × ϕ52 × 15)
Load: 7 060N
Speed: 1 600 rpm

Fig. 8 Progress of fatigue of sealed-clean bearing

1.2 Early development for automotive transmissions

In 1978 the first mass-production of sealed-clean bearings started for a light truck transmission. And in 1979 the bearing started to be used for the transaxle of a front wheel drive car. Within a few years, most of the car manufacturers in Japan started to adopt “sealed-clean” because of its tremendously long life. In the USA, Germany, Italy and also other nations, the bearing has been welcomed as a long life bearing.

The double row type of sealed-clean bearing was also introduced on the market in 1978 for passenger car transmissions.

2. Characteristics of Sealed-Clean Bearing

The sealed-clean bearing is a long life bearing because of the seal, but the seal also changes some characteristics of the bearing.

2.1 Seal character and oil passage

The seal of the sealed-clean bearing does not perfectly shut off the oil. The test result of an actual manual transmission is shown in Fig. 9. The oil enters the bearing and the quantity increases then stabilizes. Enough oil has passed the seal to the inside of the bearing within a few hours of the start. Even if no oil had passed the seal, the sealed-clean bearing has its initial grease to prevent shortage of lubricant. This seal cannot perfectly protect from contamination entering the bearing. Very small particles, for example under 10 micrometers, of contaminants have a chance to go into the bearing. But the size and quantity of contamination which is rolled over the raceway is far less than occurs in standard open bearings, so the influence of contamination is very limited.

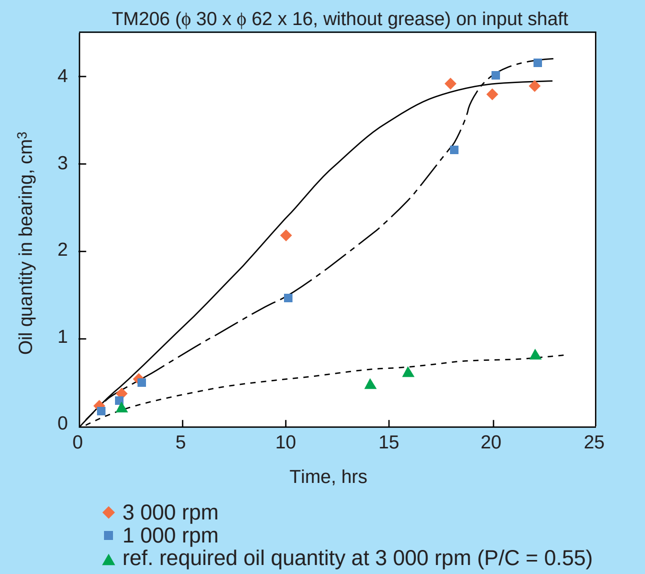


Fig. 9 Oil entry to sealed-clean bearing in transmission

2.2 Seal torques

Seal torque is a possible disadvantage of the sealed-clean bearing because it may reduce the efficiency of the transmission. The measurement results of seal torque are shown in Fig. 10. The seal torque is influenced by the interference of seal lip to inner ring, and slightly increases with bearing speed. The value is in any case not so large as for a standard oil seal.

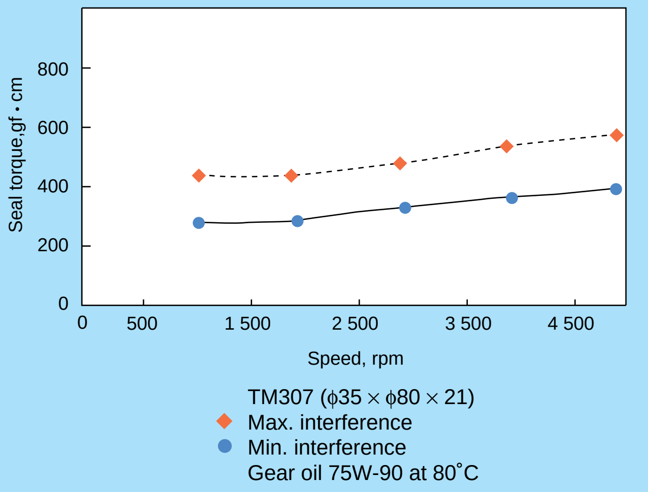


Fig. 10 Seal torque (single side)

2.3 Starting torque at low temperature

Starting torque at low temperature affects the difficulty of shift at cold start in winter in cold climates. The starting torques of sealed-clean and standard bearings are compared (Fig. 11). The starting torque is mainly influenced by the bearing rolling torque which is increased by the high viscosity of the transmission oil at low temperature. The effect of the seal torque is small.

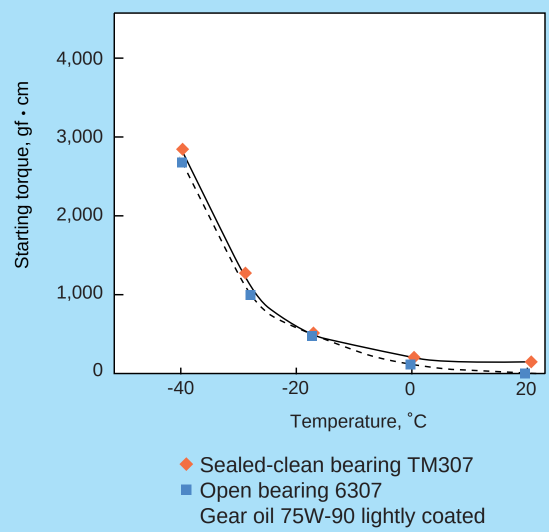


Fig. 11 Starting torque at low temperature

2.4 Bearing temperature

Seals block the oil flow, so heat generation in the bearing is difficult to remove by oil flow. Temperatures inside and outside of the bearing were measured under heavy loaded conditions. The results are shown in Fig. 12. The difference between inside and outside the bearing was less than 5°C. This value is not so large and will not affect bearing life or seal material.

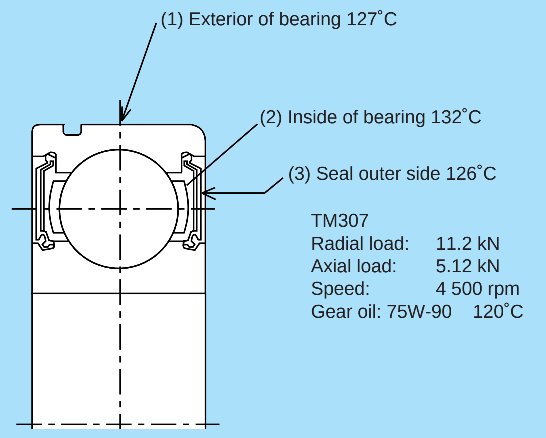


Fig. 12 Operating temperature of sealed-clean bearing

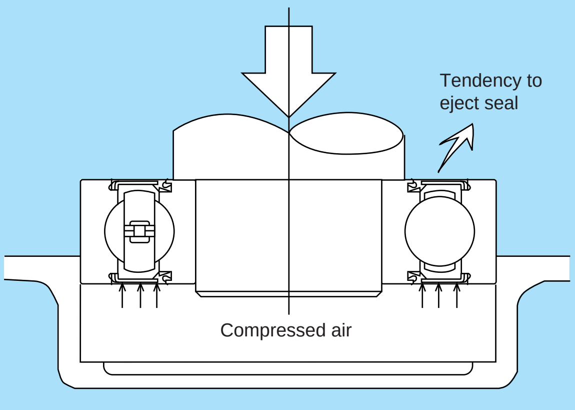


Fig. 13 Blind hole type housing

2.5 Differential air pressure inside the bearing

The seal has a pressure release hole (breeze hole) to release any internal pressure increase and make sure the seal is not forced out of the outer ring, or conversely to ensure that the seal lip is not vacuumed onto the inner ring by internal low pressure. Even if this hole became closed by grease, tests have shown that the air would release itself through the hole at 0.13 to 0.15 kgf/cm^2. This value is lower than the seal removal force. In the opposite case the low pressure is released from the seal lip side just after starting, so there is no possibility of causing severe wear of the lip. But it is necessary to avoid the “blind hole type housing”, like Fig. 13, as it may cause a sudden pressure increase during installation which can force the seal out of the bearing.

3. New Developments of the Sealed-Clean Bearing Concept

3.1 New rubber as seal material at high temperature

In response to the demand for high-temperature operation of transmissions, the seal material needs elasticity to maintain contact with the inner ring seal groove. Acrylic elastomers have enough elasticity in these high-temperature environments. Fig. 14 shows the seal lip deformation in high-temperature oil under a static thrust condition. Compared with nitrile rubber, the acrylic elastomer has less deformation. It is very effective when reversing thrust load is applied to the bearing. Fig. 15 and Fig. 16 show the surface of a sealed-clean bearing raceway after application of a reversing thrust load to test the effect on seal lip clearance. With a nitrile seal there are many dents in the raceway, but in the acrylic seal case there are very few. The change of hardness at the seal lip in high-temperature oil is also shown in Fig. 17.

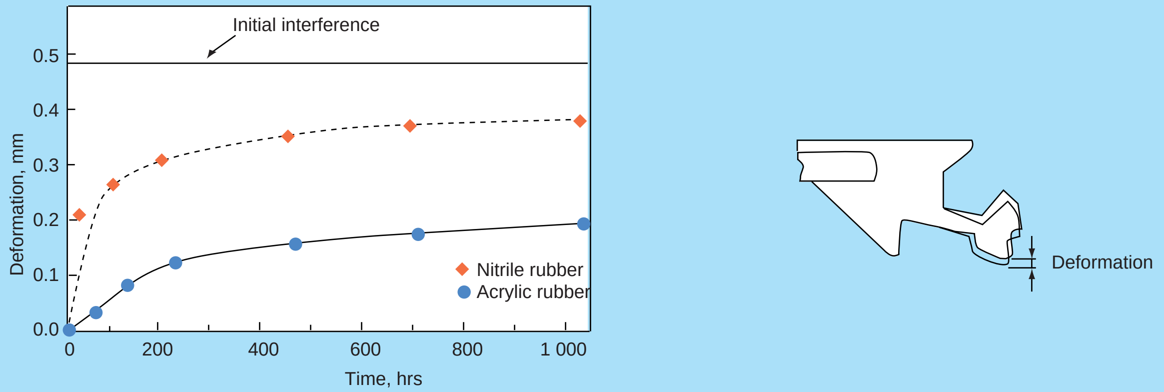


Fig. 14 Seal lip deformation at high temperature

3.2 Improvements in bearing material

For long life under contaminated conditions, the seal is the most effective countermeasure. The strategy to achieve long life is shown as a tree diagram in Fig. 18. As mentioned before, the seal cannot perfectly shut down the contamination so material improvement is also needed to be effective. Special heat treatment (UR) is the most popular way to reinforce bearing steel with nitriding. Fig. 19 shows the rolling fatigue life effect and matrix (C+N)%.

Another material improvement to carburizing steel is HTF material. HTF material uses a new 0.4% base carbon steel and carbo-nitriding to get the desired high level of retained austenite and high hardness together on the surface of a rolling raceway. It can achieve a long life under contaminated conditions (Fig. 20).

Nowadays the HTF specification can also be used for the sealed-clean bearing to gain the benefit of high dimensional stability especially at high temperatures. Fig. 21 shows the features of HTF compared to other materials.

These material improvements assist the seal effect. The results show the long life type sealed-clean bearing test result in Fig. 22 compared with conventional open-type ball bearing and standard-type sealed-clean bearing performances.

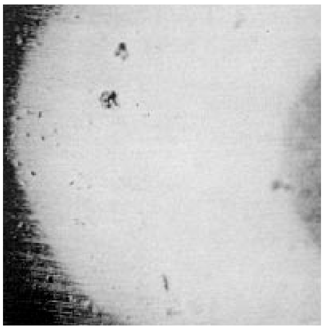


Fig. 15 Raceway of nitrile rubber-sealed bearing

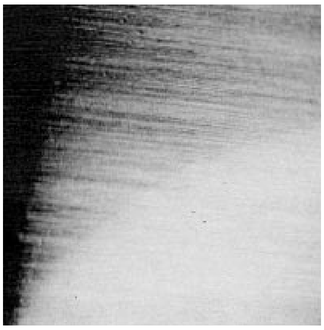


Fig. 16 Raceway of acrylic rubber-sealed bearing

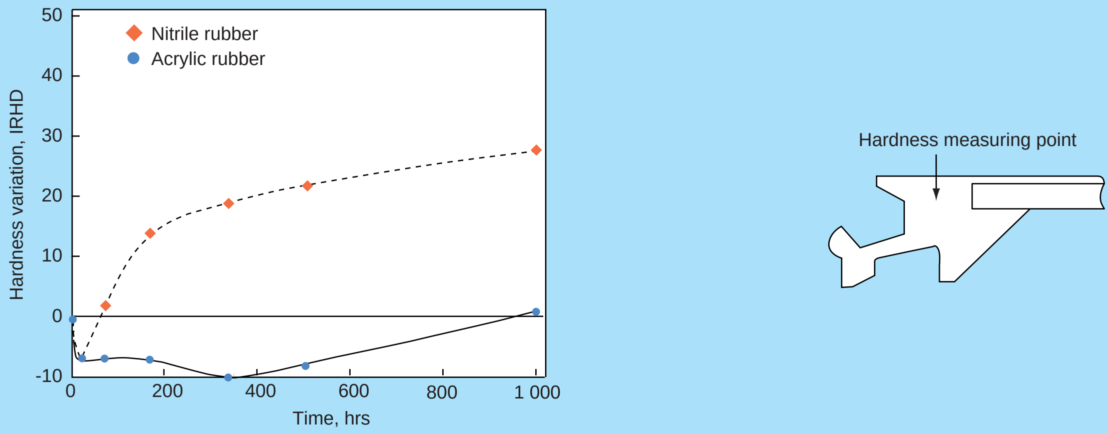


Fig. 17 Hardness change of seal lip submerged in high-temperature oil

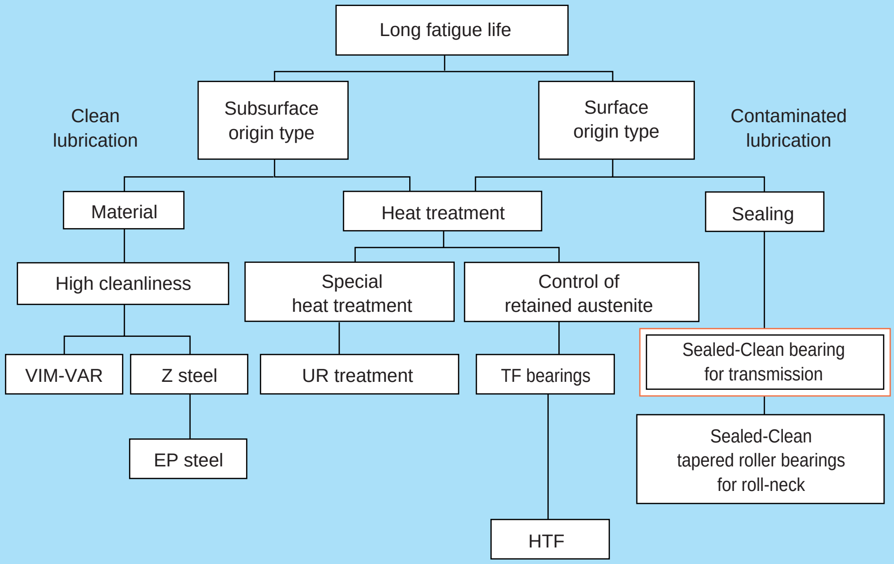


Fig. 18 Approaches to longer bearing fatigue life

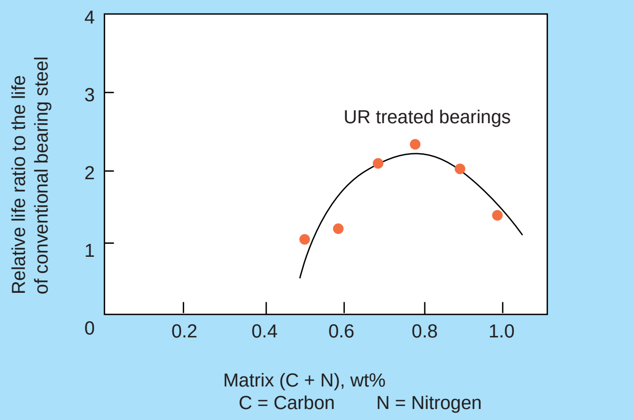
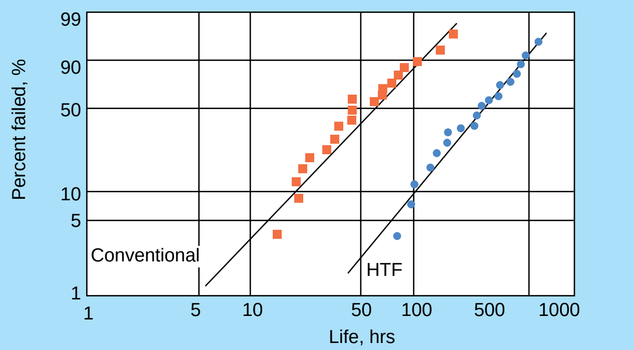


Fig. 19 Relation between matrix (C + N)% and rolling life Progress of bearing steel application and manufacturing techniques



Bearing number: 6206
Load: 6 280N
Speed: 3 000rpm
Lubrication: ISO VG68
Temperature: 65˚C
Contamination: Hardness Hv540
Size 70 to 147µm, 1000ppm

Fig. 20 Life test of ball bearings with contaminated lubrication

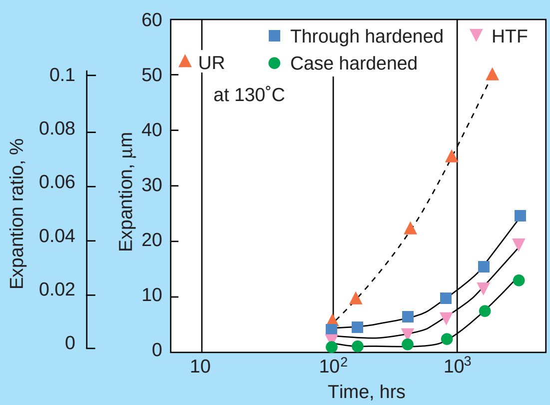
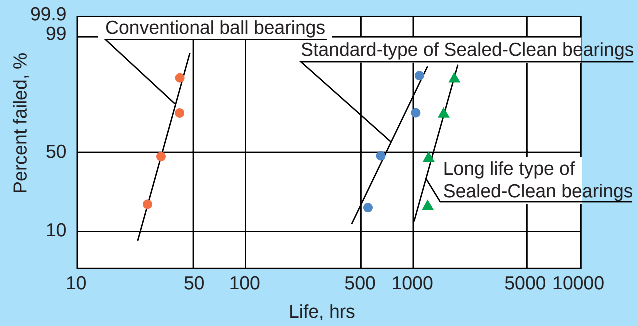


Fig. 21 Dimensional stability of outside diameter of outer ring of tapered roller bearing L44610 at 130°C



Bearing: Sealed-Clean bearing (ϕ35 × ϕ80 × 23, Cr = 39 500N, Cor = 21 500N)
Radial load: 11 231N
Axial load: 5 116N
Load ratio P/Cr: 0.32
Speed: 4 500rpm
Lubricant: Gear oil (contaminated)

Fig. 22 Long life sealed-clean ball bearings in contaminated oil

3.3 Low torque type

Low bearing friction torque is another requirement to get a high efficiency of transmission. NSK has been developing a new type of seal for Sealed-Clean bearings. Fig. 23 shows the new seal lip design which reduces the pressure at the contact zone to achieve lower torque compared with the earlier design whilst maintaining the required sealing properties. The result of seal torque measurements in Fig. 24 shows the effect of design change regarding lower torque.

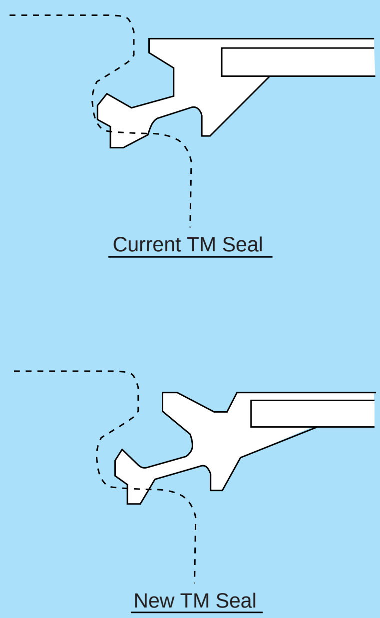
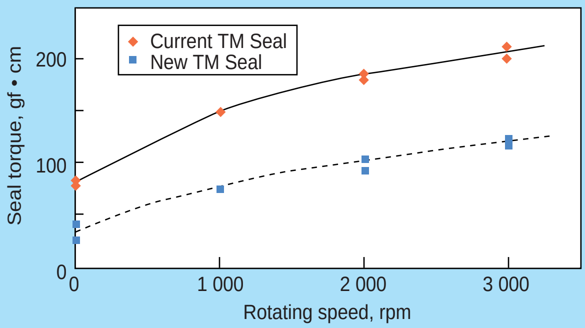
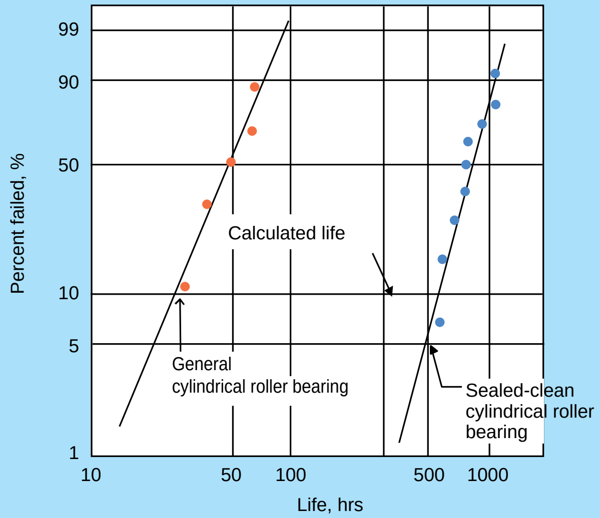


Fig. 23 Seal lip design



Seal reference: S TM206 (Bearing size : ϕ30 × ϕ62 × 16)
Seal lip interference: Mid.
Lubrication: Gear oil spread on the inner ring seal land
Ambient temperature: 100˚C

Fig. 24 Seal torque comparison



Bearing: ϕ25 × ϕ60 × 24.5, Cr = 64 000N
Load: 17 493N
Load ratio P/Cr: 0.27
Speed: 4 000rpm
Lubricant: Gear oil (contaminated)
Temperature: 120˚C

Fig. 26 Cylindrical roller bearing life test under contaminated lubrication

3.4 Sealed-clean roller bearing

Recognizing that the requirement for long life also applies to roller bearings, we have also developed the Sealed-Clean cylindrical roller bearing shown in Fig. 25. The seals keep debris out and are made of a similar high temperature resistant rubber material. The seal shape is designed to present its running lip correctly and not to accidentally permanently deform after installation even though the inner ring is inserted after the outer ring, seal, cage and rollers have already been assembled into the transmission case. Although some minute debris gets past the seal, a longer life is still further ensured because the HTF specification inhibits flaking and extends the bearing life even in the presence of debris. The life test result under contaminated conditions is shown in Fig. 26. The Sealed-Clean cylindrical roller bearing achieved a life that was 10 times longer than that of a general bearing.

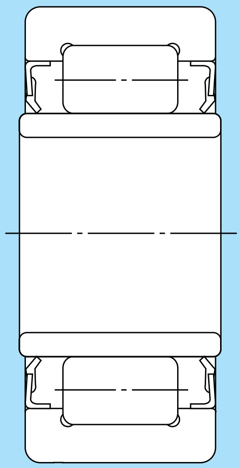


Fig. 25 Sealed-clean cylindrical roller bearing

4. Conclusion

The Sealed-Clean bearing was developed 20 years ago as a bearing with amazingly long life, but it has been improved continuously. Many characteristics have been analyzed. New high-temperature seal rubbers resistant to transmission oils, new raceway material and heat treatment have been introduced. Seal designs have been refined and the cylindrical roller bearing version was also developed. Over 900,000 Sealed-Clean bearings per month are now mass produced by the NSK Group (Appendix).

References:

1) Furumura, K., Tanaka, A., and Ohkuma, T., “Highly Extended Life of Transmission Bearings of Sealed-Clean Concept,” SAE Technical Paper 830570 (1983).
2) Beerbower, M., Shiratani, T., Murakami, Y., Abe, K. “Fighting Debris: Increasing Life with HTF Bearings for Transmissions,” SAE Technical Paper 940728 (1994).
3) “Sealed Clean Cylindrical Roller Bearings,” Motion and Control, NSK Ltd., No.1 (1996) 44-45.
4) NSK Corporate report (1980).

Appendix:
Actual use of sealed-clean bearing

(more than 1000 pcs/M only)

Bore dia.	Outer dia.	Width	Bearing No.	C (N)	C_0 (N)	Monthly production
17	40	12	TM203	9,550	4,800	7,000
17	47	14	TM303	13,600	6,650	1,000
20	47	14	TM204	12,800	6,600	22,800
20	47	16	B20-122	14,700	7,250	16,000
20	49	16	20TM06	14,700	7,150	4,000
20	52	15	TM304	15,900	7,900	2,000
22	56	16	TM3/22	18,400	9,250	1,000
22	62	17	22TM06	23,700	12,200	21,000
22	68	18	22TM07	26,700	14,000	4,900
25	52	15	25TM10	15,300	8,100	2,000
25	52	15	TM205	14,000	7,850	42,200
25	52	23.6	BD25-9	21,300	17,700	19,000
25	60	27	25TM21	23,600	12,100	12,000
25	62	17.5	25TM08A	23,700	12,200	6,000
25	62	17	25TM15	23,700	12,200	10,000
25	62	17	TM305	20,600	11,200	124,500
27	68	18	27TM01	26,700	14,000	12,000
28	52	12	TM0/28	12,500	7,400	15,000
28	58	16	TM2/28	16,600	9,500	33,000
28	68	18	TM3/28	26,700	14,000	38,000
29.2	72	17	29TM01	25,700	15,300	6,000
30	62	16	TM206	19,500	11,300	66,200
30	63	17	30TM14	23,400	12,800	54,000
30	65	18	30TM19	25,000	13,900	5,300
30	72	17	30TM04	25,700	15,300	2,500
30	72	19	30TM05	29,800	15,800	4,500
30	72	20	30TM13	32,500	17,200	17,000
30	72	19	TM306	26,700	15,000	57,000
30	75	21	30TM11	33,000	17,700	23,000
30	80	20	30TM12	33,500	19,200	7,700
32	75	21	32TM04	33,000	17,700	31,000
32	75	20	TM3/32	29,900	17,000	41,000
32	80	23	32TM03	39,500	21,500	3,000
33	80	19	33TM01	33,500	19,300	10,000
35	72	17	TM207	25,700	15,300	11,000
35	80	20	35TM10	33,500	19,200	8,500
35	80	23	35TM11	39,500	21,500	23,000
35	80	21	TM307	33,500	19,200	17,500
40	80	18	TM208	29,100	17,900	25,100
40	90	25	40TM02	47,000	26,200	4,000
40	90	23	TM308	40,500	24,000	14,000
40	92	25.5	40TM05	51,000	28,300	12,000
40	92	25.5	40TM08	51,000	28,300	2,000
40	100	25	40TM06	53,000	32,000	1,500
45	100	28	45TM01	59,500	33,500	2,000
45	100	25	TM309	53,000	32,000	16,200
45	400	29	45TM04	66,500	40,500	5,000
50	90	20	TM210	35,000	23,200	10,000
50	110	27	TM310	62,000	38,500	800
50	115	32	50TM02	73,000	42,500	5,000
55	120	29	TM311	71,500	44,500	1,100

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