Development of a Low Contamination Generation Bearing for Servo Motors

Araki TANAKA* Naoaki TSUJI**
Hideyuki MITANI** Takayuki KAWAMURA***

NTN has developed low contamination generation bearings for servo motors and has experienced increased demand for these bearings in recent years. This bearing type generates 90 % less contamination and requires 50 % less torque than conventional bearings; this allows the servo motor to be downsized and increases the motor's power output. This report introduces the features and performance of the low contamination generation bearing.

1.Introduction

With increasing demand for improved productivity and reduced labor costs against the backdrop of a diminishing working population, performance improvement is required for FA devices and motors **(Fig. 1)**, the power sources of devices such as machine tools and industrial robots[1)].

NTN has recently developed a low contamination[*1] generation bearing to decrease the size and increase the power output of servo motors for industrial robots.

In addition to technical trends for servo motor bearings **(Fig. 2)**, this developed product's features and evaluation test results are introduced below.

Fig. 1 Motor

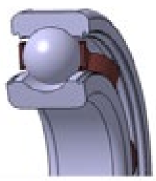


Fig. 2 Servo motor bearings

2.Development Background

In recent years, demand for servo motors for use in machine tools and industrial robots has increased. A servo motor features a rotation detector and brake, or control device, that enable it to control rotation with a high level of precision. Generally, a sealed and greased deep groove ball bearing with cost advantages is used in a servo motor to support high speed rotation. **Table 1** shows the characteristics required for servo motors and their supporting bearings.

Table 1 Requirements of Servo Motor Bearings

Application	Required Servo Motor Characteristics	Required Bearing Characteristics	Other Bearing Characteristics
Machine tool	High speed rotation	High speed rotation	Plastic ribbon cage
		Long grease life	ME-1 Grease
Industrial robot	Compact	Low contamination generation	Low contamination generating grease
	High power output	Low torque	Contact seal

Servo motors used for machine tools rotate at high speeds and are often used to drive a spindle. Therefore, the bearing must have good high speed rotational performance and a long grease life. **NTN** has historically used "ME-1"[3)] high temperature, long-life grease and its proprietary "plastic ribbon cage" **(Fig. 3)**. This cage has the advantage of extending the grease life and prevents centrifugal expansion that inhibits high speed rotation. **NTN** also offers its commercialized[4)] "ULTAGE[*2] Deep Groove Ball Bearings for High-Speed Servo Motors" **(Fig. 4)** that combine long operating life with high speed rotation at a $d_m n$ value[*3] of 1 million.

Fig. 3 Plastic ribbon cage[2)]

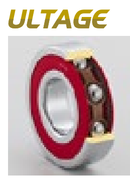


Fig. 4 ULTAGE deep groove bearings for high-speed servo motors[4)]

*1 Throughout this report, contamination refers to lubrication emitted by the bearing.
*2 ULTAGE is the name for **NTN**'s new generation of bearings that is noted for its industry-leading performance. The name is created by combining "ultimate", signifying refinement, and "stage", signifying **NTN**'s intention for this product to be used for a variety of applications.
*3 $d_m n$ is a value that represents the bearing's rotational performance.
$d_m n = d_m$(bearing rolling element pitch diameter, mm) × n(rotational speed, min^{-1})

* Application Engineering Dept., Industrial Business Headquarters
** Product Design Dept., Industrial Business Headquarters
*** Advanced Technology R&D Center

Servo motors used in industrial robots are often used to drive joints and, like those used in machine tools, are required to be compact. These bearings must also generate a high power output to increase the axis speed and acceleration/deceleration rates of the joints they support. A control device is typically mounted near the bearings of industrial robots. However, bearing lubrication can splash onto and stick to these control devices which causes a drop in detection accuracy and braking performance. To prevent this, sealed device could be used to protect the control device, but this increases the size of servo motor and results in a less compact system. A low contamination generation bearing is required to prevent lubrication from exiting the bearing and sticking to the control device when a servo motor does not equip sealed device between its bearing and control device. Furthermore, low torque generation is required to achieve high power output from the servo motor. **NTN** has therefore commercialized a low contamination generation bearing[1] that utilizes a seal arrangement that prevents pressure from increasing inside the bearing, the main cause of contamination generation, and requires low torque. This bearing also uses "EP-1" grease, a low contamination-generating grease. Each year the requirements for low contamination generation and low torque become more stringent, and further performance improvement is required.

3.Product Structure and Features

The "Low Contamination Generation Bearing for Servo Motors" **(Fig. 5)** is a deep groove ball bearing with a newly developed low contamination-generating grease and a newly developed contact seal on both sides of the bearing. In comparison with conventional **NTN** products, this bearing both reduces the amount of contamination generated by the bearing by approximately 90 % and the rotational torque by approximately 50 %.

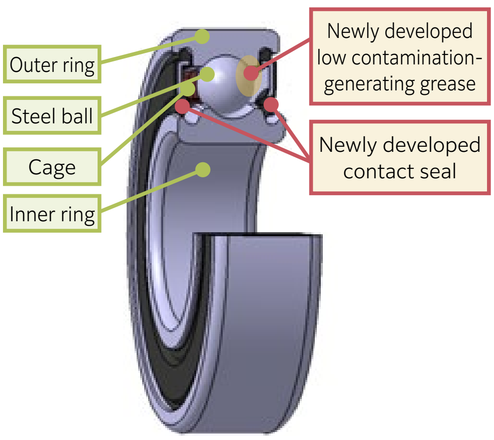


Fig. 5 Low Contamination Generation Bearing for Servo Motors

3.1 Low Contamination Generating Grease

When bearings rotate, compressive and shearing forces are applied to the grease within the bearing. This causes the base oil to separate from the thickener. Furthermore, fine particles are released.

As explained in section 2, lubrication can exit the bearing and splash onto the servo motor control device. After collecting and analyzing this contamination, **NTN** found it to be a component of the base oil. However, the grease thickening agent was not detected. It is therefore necessary to prevent the base oil in the grease from separating and evaporating **(Fig. 6)**. More specifically, increasing the surface tension of the base oil[5] and decreasing the grease consistency is considered to be effective for low contamination generation. The following pages show the test results that confirm this effect.

Furthermore, since contamination generated by the bearing is caused by heat generated by bearing rotation and internal bearing pressure increase, it is also necessary to devise a means to stop the internal bearing pressure from rising.

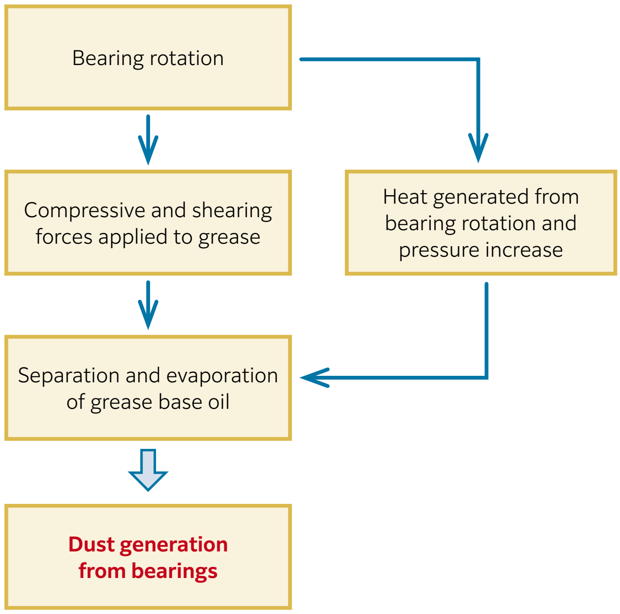


Fig. 6 Dust generation from bearings

1) Relationship Between Base Oil Surface Tension and Contamination Generation[5)]

16 types of bearing lubrication with different base oil surface tensions were applied onto test bearing part number 608 with an average thickness of 1 μm. The amount of contamination generated was then investigated while rotating the test bearing inner rings at a speed of 1,000 min^{-1} with an axial load (Fa) of 10 N. A light scattering particle counter with a total volume of 9 L was used to count particles of contamination with sizes of 0.1 μm or larger for 30 minutes. The trial was then continued for 8 total hours. **Fig. 7** shows the results.

A distinct trend was observed: the higher the base oil surface tension, the smaller the amount of contamination generation at both the initial stage of rotation and after 8 hours had elapsed. This means that selecting a base oil with a high surface tension can be effective for low contamination generation.

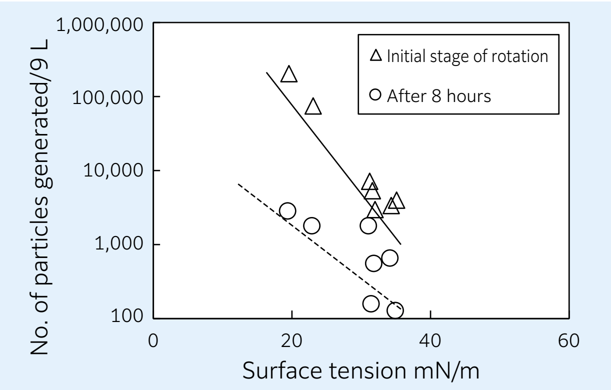


Fig. 7 Relationship between base oil surface tension and contamination generation

2) Relationship Between Consistency and Contamination Generation

After adjusting the type and amount of thickening agent, 16 test grease types, 8 with thickening agent A and 8 with thickening agent B and all with different trial consistencies, were applied on test bearing part number 608 with a total weight of 0.1 g. The same test method used in section 1) above was used to calculate the amount of contamination generated after 8 hours of testing had elapsed. **Fig. 8** shows the results.

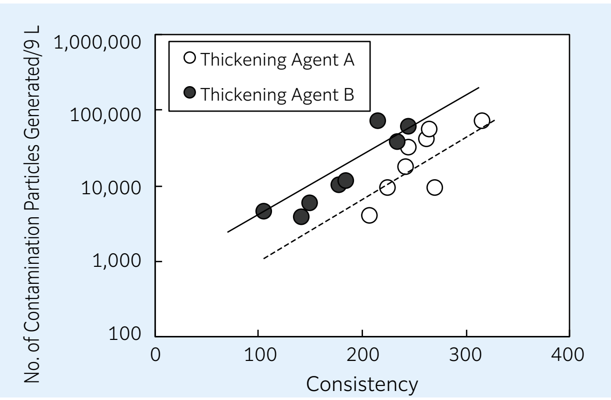


Fig. 8 Relationship between grease consistency and contamination generation

Another distinct trend was observed: the lower the consistency of the grease, the smaller the amount of contamination generation for both of the tested thickening agents. This means that optimizing the type and amount of thickening agent to achieve low grease consistency can be effective for low contamination generation.

Selecting a base oil with a high surface tension and optimizing the type and amount of thickening agent **(Table 2)** reduces the contamination generated by approximately 60 % compared to "EP-1", the current low contamination generation grease **(Table 3, Fig. 9)**.

In addition, this developed grease satisfies the requirements for high temperature durability and wear resistance for servo motor applications. An appropriate additive was selected that has no adverse effect on the base oil's surface tension and consistency.

Table 2 Characteristic of the developed grease

	Developed low contamination generation grease	Current grease EP-1
Thickening agent	Urea	Urea
Base oil	Synthetic oil	PAO
Base oil viscosity, mm^2/s (40 ℃)	130	47
Mix consistency, 60 W (25 ℃)	220	220

Table 3 Condition for contamination generation test

Test bearing	6900	Axis orientation	Vertical
Load condition	Fa = 30 N	Test temperature	Constant 120 ℃
Rotation speed	Constant 6,000 min^{-1}	Test time	200 hours

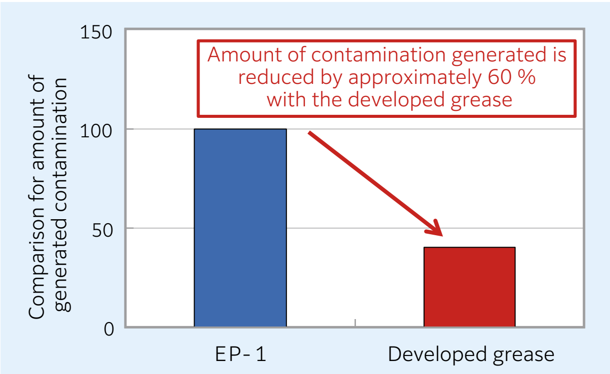


Fig. 9 Contamination generation test of the developed grease*

* The contamination generation test used a test machine that simulates a servo motor. A glass plate that simulated a rotation detector was used to measure the mass of oil that stuck to the glass plate.

3.2 Low Contamination Generation, Low Torque Seal

As described in section 3.1, in order to reduce contamination generated by the bearing, pressure increases inside the bearing should be prevented. To help prevent this internal bearing pressure, a contact seal can be installed on the control device side and a non-contact seal can be installed on the opposite side. This allows air intake/exhaust through the bearing and prevents pressure differential from occurring between the interior and exterior of the bearing.

In recent years, control devices are installed on both sides of the bearing, necessitating low contamination generation on both sides of the bearing. Furthermore, low bearing torque is required to increase servo motor power output.

The newly developed **NTN** contact seal adopts the following two points compared to a conventional contact seal **(Fig. 10)**.

① A slit is added to the seal outer diameter to allow air intake/exhaust through the bearing.
② The shape of the seal lip is changed.

To confirm the effect of this seal slit ①, a seal was installed on one side of a bearing and oil was injected into the opposite side to check whether oil seeped out of the slit. This indeed resulted in oil seeping through the slit and confirmed air intake/exhaust air through the bearing is possible **(Fig. 11)**.

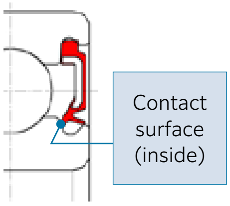
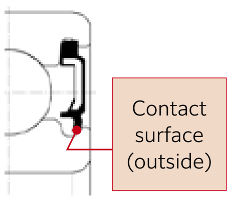
	Conventional seal	Developed seal
① Slit		
② Seal lip		

Fig. 10 Characteristics of the Developed Seal

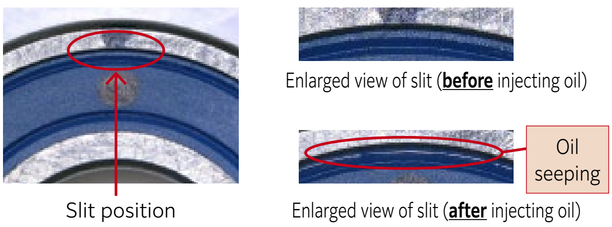


Fig. 11 Performance test of the seal slit

Furthermore, for conventional seals, the seal lip makes contact with the inside of the inner ring seal groove. In contrast, the lip of the developed seal makes contact with the outside of the seal groove. This ensures interference between the seal lip and inner ring seal groove and prevents contamination from exiting the bearing, even when the pressure inside the bearing increases and the seal lip deforms towards the outside of the seal groove.

If the seal lip of a conventional seal that makes contact with the inside of the seal groove deforms towards the outside of the bearing, the seal/inner ring interference, tension force of the seal lip, and rotational torque will increase. The developed **NTN** seal prevents this seal lip tension force from increasing when interference increases due to the shape of the seal lip **(Fig. 12)**.

Table 4 and **Fig. 13** show the bearing rotational torque with usage of the developed seal. The developed seal reduces the rotational torque by approximately 60 % compared to the conventional seal.

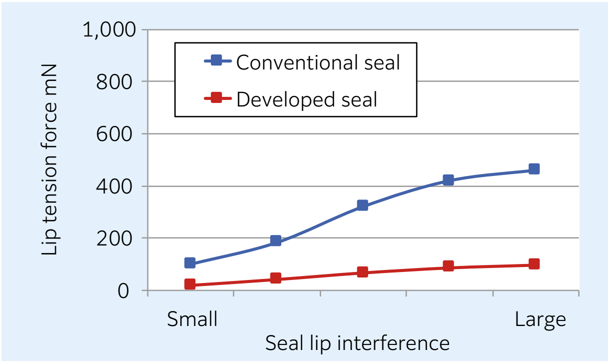


Fig. 12 Relation between seal lip interference and tension forth (FEM analysis)

Table 4 Conditions for Torque Test

Test bearing	6900 (φ 10 × φ 22 × 6) Each seal installed only on one side
Load condition	Fa = 39 N
Rotation speed	Constant 3,600 min^{-1}
Axis position	Vertical axis
Lubrication	Small quantity of VG32 oil applied

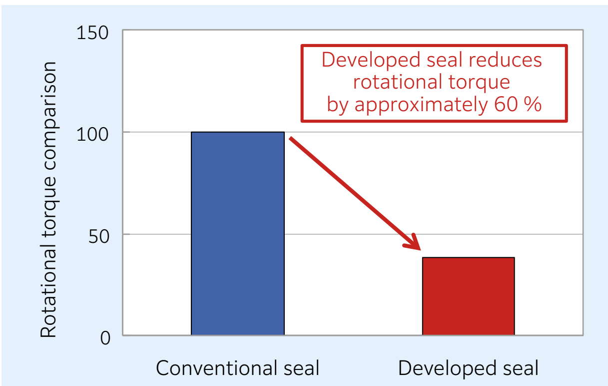


Fig. 13 Torque test of the developed seal

4.Evaluation Test

4.1 Test Conditions

Contamination generation and rotational torque tests were conducted to evaluate the performance of this **NTN** developed product. **Tables 5** and **6** show the specifications of the evaluated bearings and the test conditions for each evaluation.

Table 5 Specifications of Test Bearings

	Conventional product	Developed product
Bearing	6900 (φ 10 × φ 22 × 6)	
Seal	One side: Contact seal One side: Non-contact seal	Both sides: Contact seal (Developed seal)
Grease	EP-1	Developed grease
Amount of grease injected	Approximately 0.1 g	

Table 6 Condition for torque test

Test bearing	Same specifications as **Table 5**
Load condition	Fa = 39 N
Rotation speed	Constant 3,600 min^{-1}
Axis position	Vertical axis

4.2 Test Results

Figures 14 and **15** show the results of the contamination generation test while **Fig. 16** shows the results of the rotational torque test. The test results reinforced the conclusions drawn earlier in this report. This developed bearing both reduces the amount of contamination by approximately 90 % and reduces the rotational torque by approximately 50 % when compared with **NTN** conventional product.

The contamination generation test used a test machine that simulates a servo motor, the same as shown in **Fig. 9** in section 3.1. A glass plate was installed next to the bearing to measure contamination accumulation. **Fig. 14** shows a photo of the exterior view of the glass plate before and after the test. The cloudy section of the glass plate after the test is the result of oily substances generated by the bearing. The greater the amount of contamination generation, the thicker this cloudy section becomes. As shown in **Fig. 15**, the developed product has a lower amount of contamination generation than the conventional product.

Application of this developed bearing in a servo motor means that a sealed device is no longer necessary to prevent contamination generated from the bearing from sticking to the control device. It also enables servo motors to be more compact and results in higher power output by reducing the rotational torque of the bearing.

These factors enable further performance improvements for servo motors and can contribute towards productivity improvements for industrial robots.

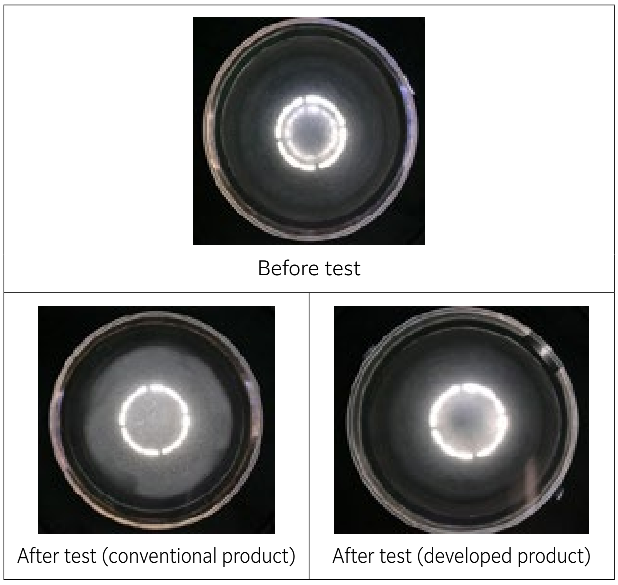


Fig. 14 Photo of Glass Plate After Testing

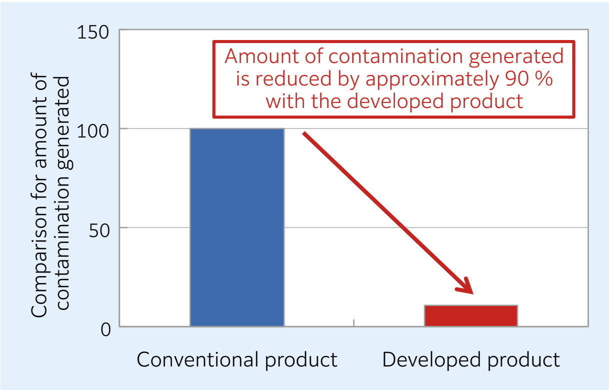


Fig. 15 Contamination Generation Test Results

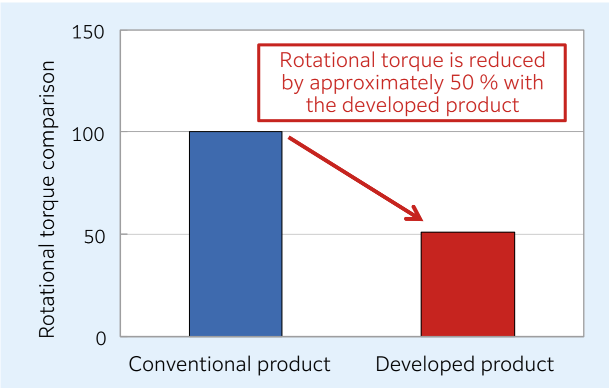


Fig. 16 Torque test of the developed bearing

5.Summary

With increasing demand for improved productivity and reduced labor costs against the backdrop of a diminishing working population, performance improvement is required for FA devices and motors, the power sources of devices such as machine tools and industrial robots.

NTN has developed the low contamination generation bearing for servo motors that significantly reduces rotational torque and generated bearing contamination to help make servo motors used in industrial robots more compact and provide higher power output.

NTN aims to further improve bearing performance and quality in the future and provide outstanding support for customer requests by strengthening its technical support and product proposals.

References

1) Hikaru Ishida, Technical Trend of Servo Motor Bearings, THE TRIBOLOGY, No.388, (2019) 42-44.
2) Chikara Katagiri, Kenichiro Naito, Next Generation Deep Groove Ball Bearing for High-Speed Servomotor, NTN TECHNICAL REVIEW, No.72, (2004) 46-51.
3) Hidenobu Mikami, Development of Long Life Grease for High Speed Application "ME-1" Grease for Motor Bearings, NTN TECHNICAL REVIEW, No.72, (2004) 20-25.
4) NTN ULTAGE Deep Groove Ball Bearings for High-speed Servo Motors, CAT.No.3103, 11. 05. 03, (2011).
5) Takayuki Kawamura, Masami Minami, Masakazu Hirata, Evaluation of Dust Generation Characteristics of Lubricating Oil due to Rolling Bearings, Japanese Society of Tribologists, Proceedings for Tribology Conference, (2000) 85-86.

Photo of authors


Araki TANAKA
Application Engineering Dept., Industrial Business Headquarters


Naoaki TSUJI
Product Design Dept., Industrial Business Headquarters


Hideyuki MITANI
Product Design Dept., Industrial Business Headquarters


Takayuki KAWAMURA
Advanced Technology R&D Center