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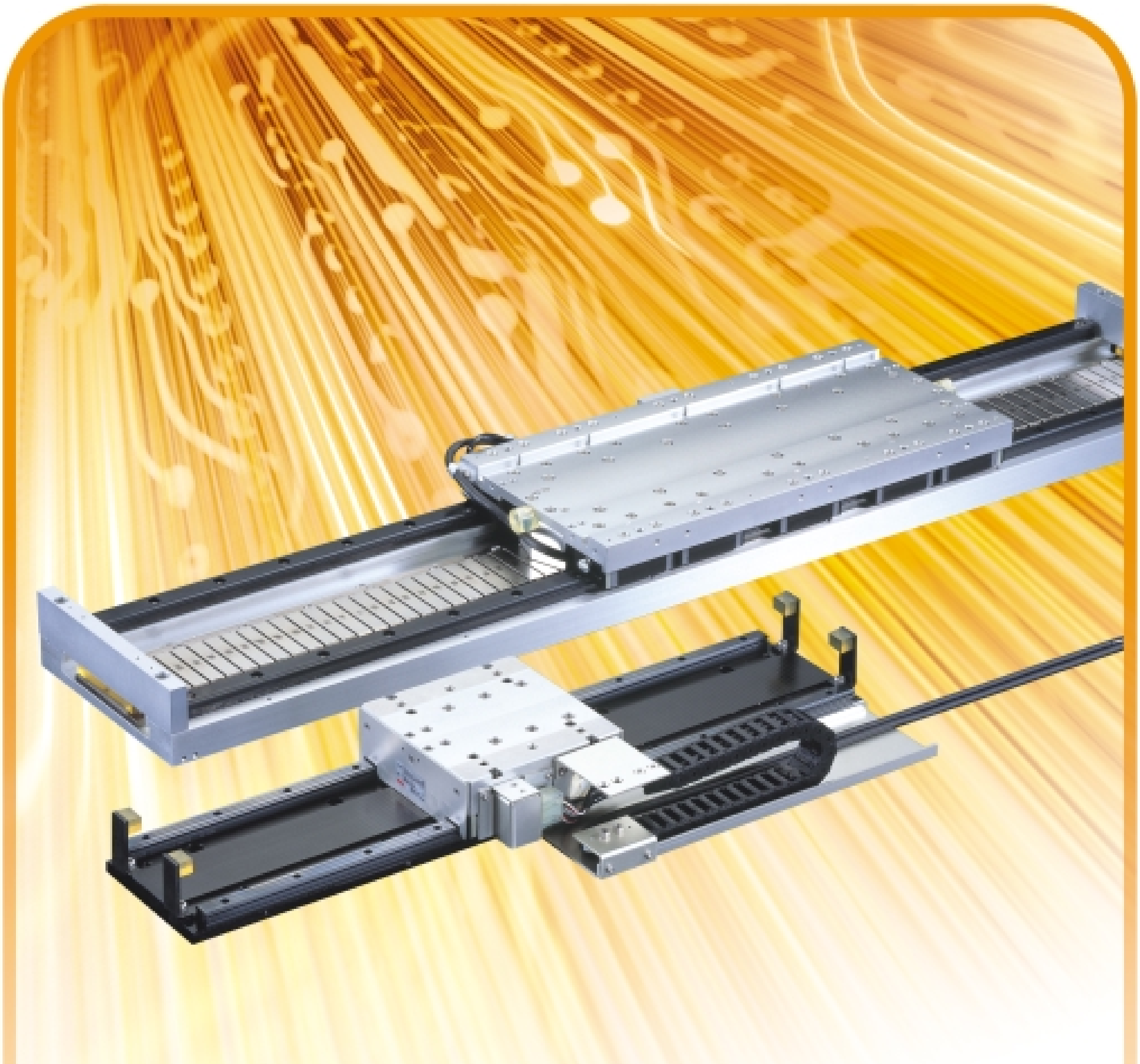

Megathrust Motor
PM Series and Y Series

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Development of Silent-running Cylindrical Roller Bearings

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Corporate Research and Development Center

ABSTRACT

In recent years, electric motors with low noise and low vibration, which have little or no impact on the environment, have become the de facto standard of electric motors.

An unpleasant metallic noise, called “squeal noise,” can be heard in the cylindrical roller bearings that are used in middle- and large-sized electric motors. Electric motor manufacturers have long requested bearings be developed that would eliminate squeal noise.

This paper reports on the results of our research, which focused on development of quieter cylindrical roller bearings and the suppression of squeal noise.

1. Introduction

In recent years, electric motors have required greater noise reduction and quieter running performance for a more comfortable environment. Therefore, rolling bearings used in motors must be modified to meet such requirements. Research and development at NSK has focused on implementing solutions to counter these new challenges.

Cylindrical roller bearings used in large- and medium-sized motors can produce an unpleasant intermittent squeal or high-pitched squeal noise. Motor manufacturers have responded with strong demands for silent-running bearings. Such noise can occur continuously or intermittently. Once it occurs, the noise level of a single bearing may increase by maximum 20 dB, which constitutes an unpleasant noise or an uncomfortable sound.

Based on the achievements of our R&D, we have developed cylindrical roller bearings with greater noise reduction and quieter running properties. This report provides further details.

Test conditions
Test bearing: NU218 (ø90 mm × ø160 mm × 30 mm)
Radial load: 1 470 N
Running speed: 1 200 min^{-1}
Lubricant (grease): Multinoc DX1, fully packed (30g)
Time: 3h

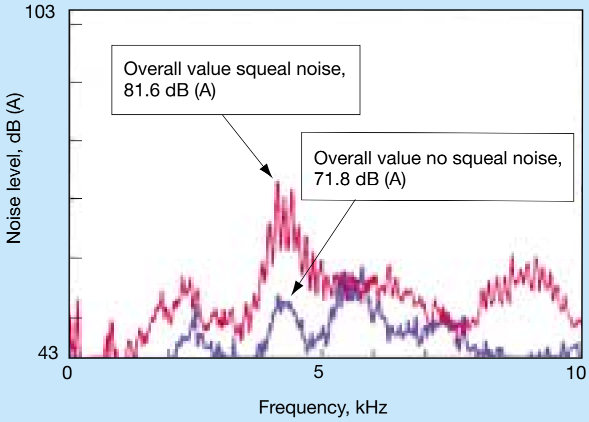

Fig. 1 Frequency analysis of squeal noise

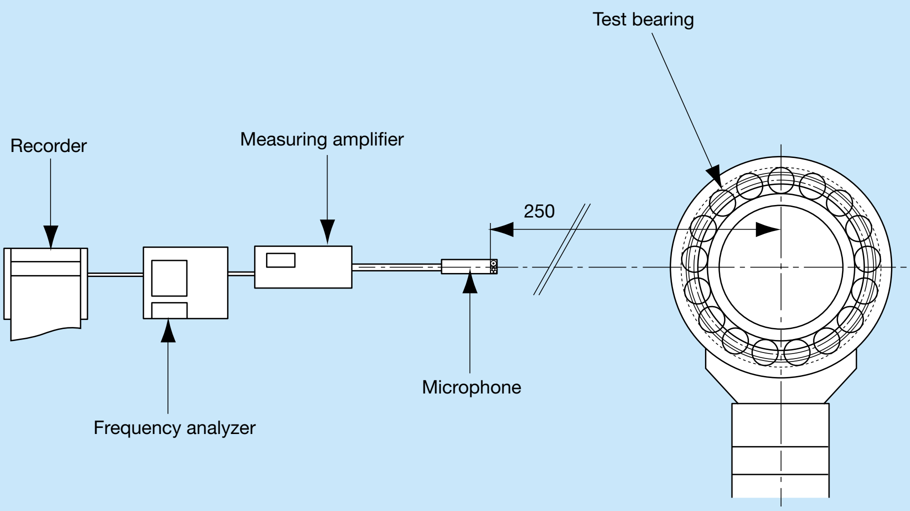

Fig. 2 Outline of squeal noise evaluation

2. Squeal Noise

Squeal noise of a bearing is a high-pitched sound, which can be quite audible at times.

This noise is likely to arise when relatively large bearings are operated under radial load. It is often associated with cylindrical roller bearings, but can occur with ball bearings as well.

The characteristics of squeal noise are as follows:

(1) Tends to occur when radial clearance is large

(2) Occurs mostly with grease lubrication and only rarely with oil lubrication. Its generation depends on the kind and amount of grease being used.

(3) Occurs more often in winter

(4) Occurs within a certain speed range that tends to become lower as bearing size increases

Influenced by the lubrication used and increasing vibration of the outer ring, the friction between the outer ring and rolling elements is considered the cause of squeal noise[2). Fig. 1 shows frequency analysis results of a bearing with occurrence and nonoccurrence of squeal noise of an NU218 bearing. Noise levels and noise level fluctuations for this particular bearing were large in the 4.5 kHz and 9 kHz regions, as shown in Fig. 1. We can see from this figure that the level of sound increases approximately 10 dB in terms of overall value within an overall frequency range of 0−10 kHz. Fig. 2 offers a schematic arrangement of the test equipment.

Aside from the unpleasant noise or uncomfortable sound, there is no other hindrance on bearing life, grease life, or bearing operation.

Effective countermeasures against squeal noise have included reducing the radial clearance and employing a very shallow groove in the outer ring raceway of the bearing, however, the countermeasures were not sufficient in some cases.

3. Silent-running Bearings

3.1 Silent-running specifications

Research at NSK has thus far revealed a close relation between squeal noise and behavior of the rolling elements in the no-load regions. In order to stabilize roller movement in the no-load regions, we examined several factors including bearing clearance, dimensional accuracy, shape, material of the outer and the inner rings, rollers and cages, as well various combinations of these factors.

As a result, we were able to develop the following specifications (Fig. 3):

1) Straightening of the contoured rolling contact surface of rollers

2) Larger guide width (*B*) and smaller guide clearance (*H*) in relation to the cages outer diameter surface area and the outer ring rib inner diameter surface area (Fig. 4).

Figure 4 shows that noise levels were lower when the bearing had a larger guide width (*B*), a smaller guide clearance (*H*), and when the rollers had a straight rolling contact surface instead of a crowned shape.

Straightening of the rolling contact surface prevents noise by stabilizing the position of the roller in the bearing, as opposed to crowned rollers whose rolling contact surface profile has an axial curvature. Furthermore, improved flow of both grease and oil

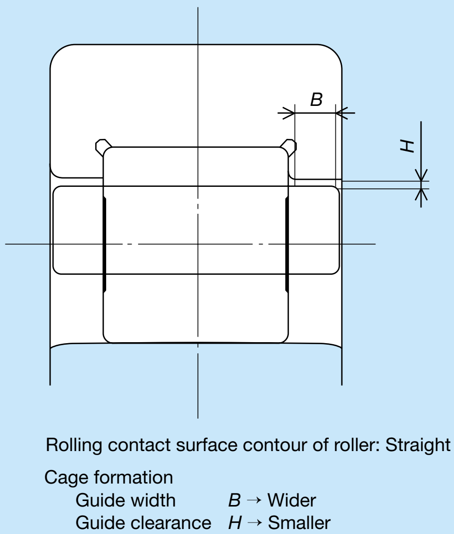

Fig. 3 Noise reduction specifications

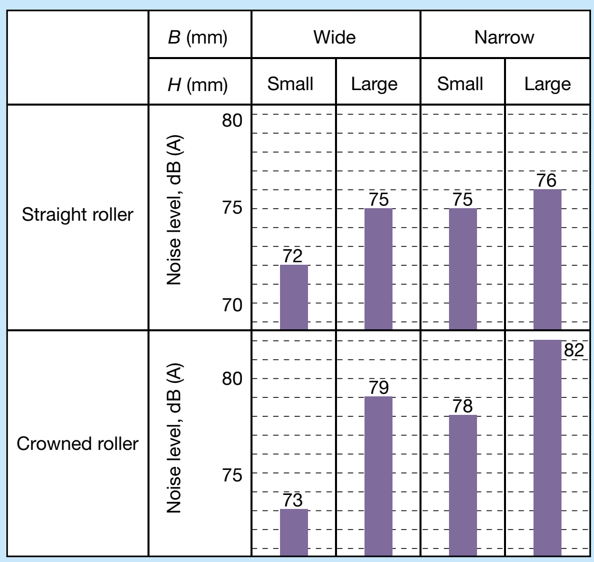

Fig. 4 Effects of noise reduction specifications

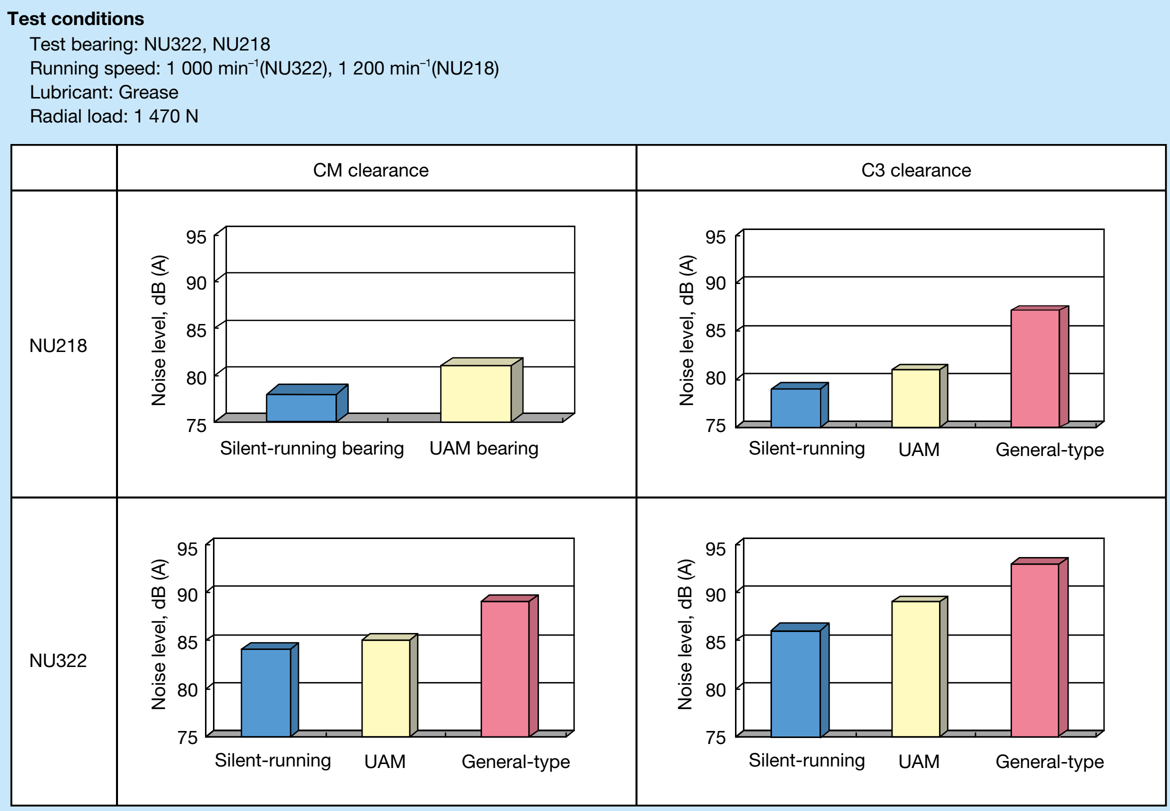

Fig. 5 Effects of radial clearance

lubricants is facilitated between the cage and the outer ring rib by increasing the width and by decreasing the clearance of the guide. Cage attenuation is increased while running speed fluctuations of the cage are reduced, allowing smoother roller movement.

3.2 Noise reduction efforts

3.2.1 Radial clearance

Since noise occurs where there is a large radial clearance, CM clearance, which is less than CN clearance, has been exclusively used for electric motors. Fig. 5 compares CM clearance, and C3 clearance, which is larger

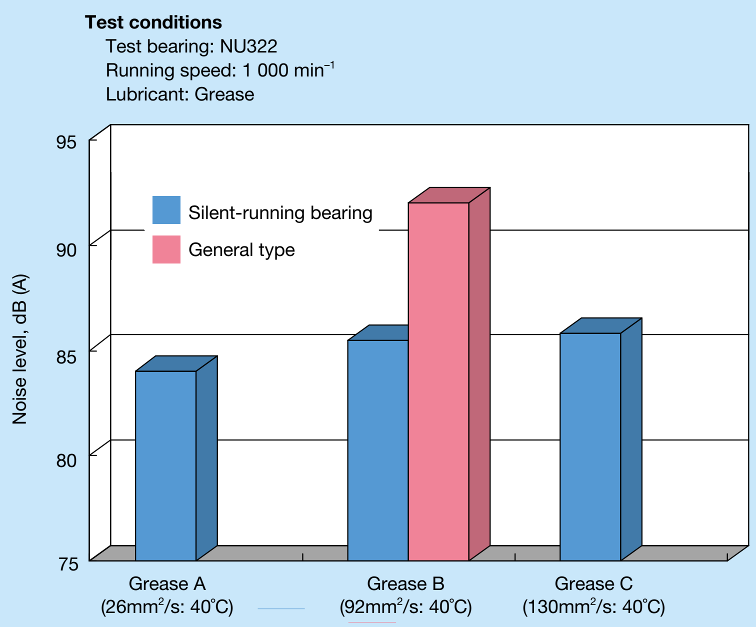

Fig. 6 Effects of various kinds of grease

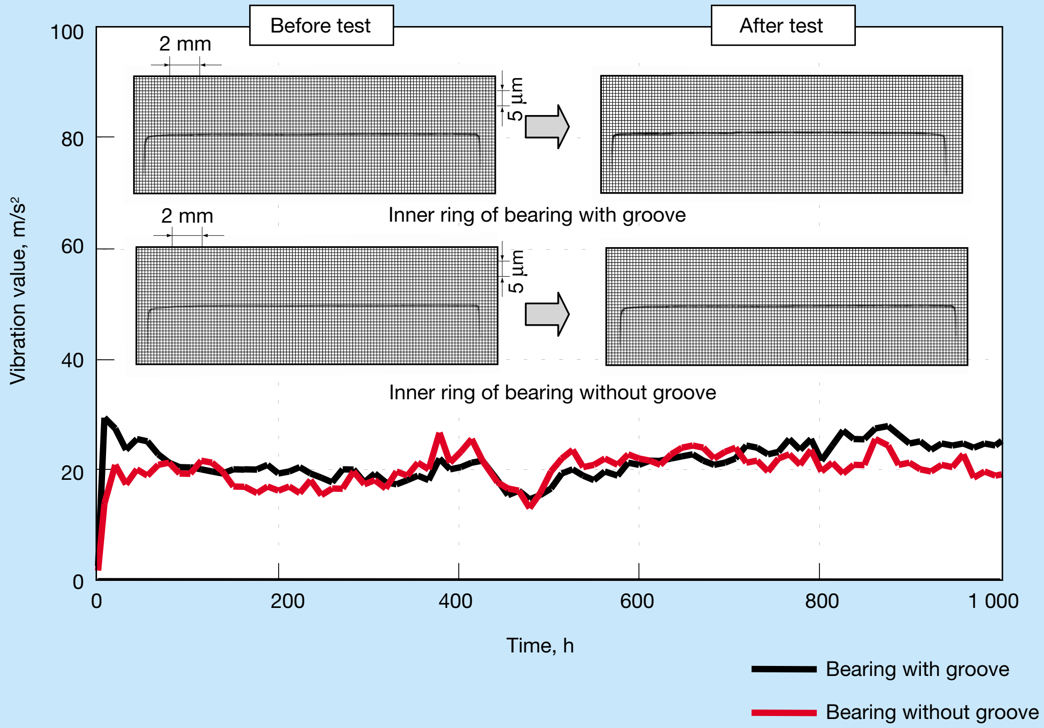

Fig. 7 Durability test results (Vibration value and deformation)

than CN clearance, for different sizes of (a) newly developed silent running bearings, (b) conventional low-noise UAM bearings, and (c) conventional cylindrical roller bearings. Noise levels of the newly developed silent-running bearings stabilized at a low level irrespective of the CM or C3 clearance. Noise levels were lower by as much as 7–8 dB compared to conventional bearings, and were lower by as much as 3–4 dB compared to conventional low-noise UAM bearings.

3.2.2 Lubricating grease

Squeal noise occurs with grease-lubricated bearings while the sound varies depending on the type of grease. The base oil viscosity of the grease also has an effect on squeal noise. Therefore, we examined the squeal noise of bearings that were lubricated with three typical types of grease having a different base oil viscosity.

Fig. 6 shows that no noise was produced in the silent-running bearing with each of the greases whose base oil viscosity was between 26 and 130 mm^2/s (at 40°C). The noise level of the silent-running bearings was also lower by about 7 dB than that of a conventional bearing when lubricated with Grease B (92mm^2/s: 40˚C), which has a base oil viscosity that lies between the other two.

3.3 Noise reduction durability test results

We conducted a durability test for 1 000 hours to determine the effectiveness of our noise reduction efforts. For this test, we used a testing machine that simulated an actual motor, and included housing for the bearings with front and rear caps to contain grease. Noise reduction efforts were applied to both of the conventional low-noise bearings that employed a shallow-groove outer ring, and a conventional outer ring.

Test results in Fig. 7 show that bearing housing vibrations remained stable at levels of about 20 m/s^2. No squeal noise was produced by either of the bearings throughout the test. Outer ring temperatures of both bearings were also similar, although the temperature of the grooved outer ring was slightly higher. These results show that with noise preventive efforts, bearings can remain relatively quiet for at least 1 000 hours regardless of the oil retaining effect of the shallow groove. The outer and inner ring raceways, rolling contact surfaces of the rollers, and guide surfaces of the cage were in good condition and free of any wear and unusual trace marks. Surface conditions of the inner ring raceway, before and after testing, are also shown in Fig. 7.

4. Development of the EM Series

NSK has developed the EM series cylindrical roller bearings equipped with a newly designed one-piece brass cage. EM series bearings, featuring noise reduction specifications and a machined cage, are now NSK's standard cylindrical roller bearings. Main features of the EM series are as follows[3]:

Photo 1 EM series bearing

(1) A newly designed, well-balanced, high-strength cage, which has gone through severe testing and theoretical analysis.
(2) The EM series cage design enables a greater number of larger rollers to be integrated resulting in up to 30% higher load capacity than that of the M series.
(3) The one-piece cage design enables enhanced accuracy in roller positioning, resulting in greater noise reductions.

Photo 1 shows a cutaway of the EM series bearing. Fig. 8 illustrates the sound measurement results of an EM series bearing. Since the EM series bearing is a standard cylindrical roller bearing with a high load capacity, noise reductions are of less concern. Regardless, noise levels are still much lower for this product than conventional M series bearings[4].

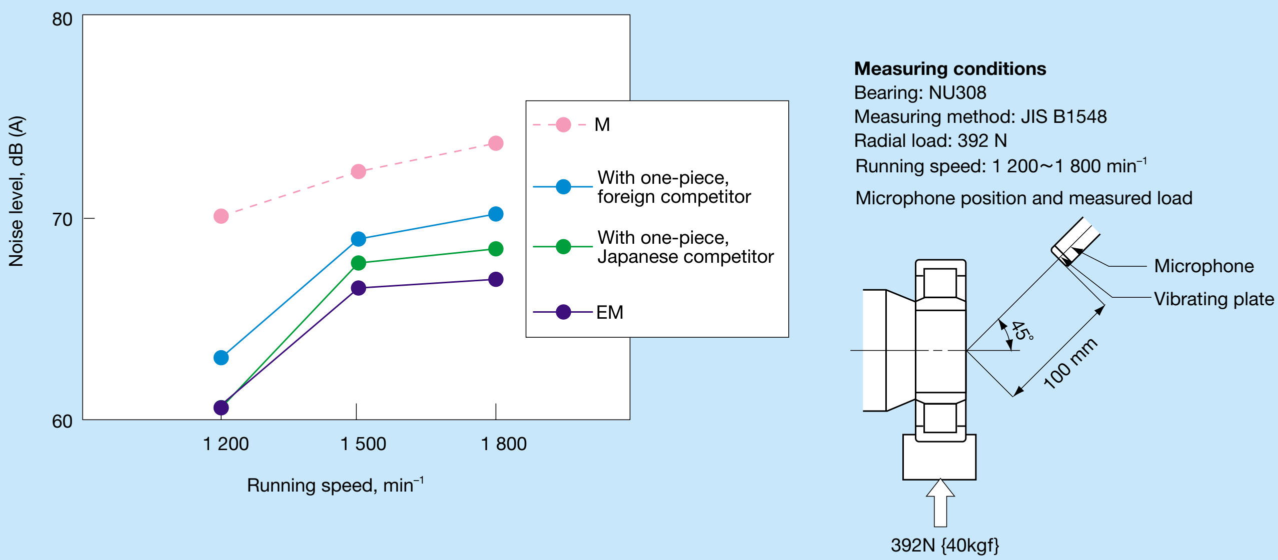

Fig. 8 Sound measurements of the EM series bearing

5. Conclusion

I have presented a summary of silent-running bearings incorporating a new design, whose performance exceeds that of conventional low-noise bearings. Under increasing requirements for lower noise and lower vibration performance, which are a part of the recent needs of the electric motor market, these newly designed bearings offer greater noise reductions, contributing to a friendlier working environment.

The quiet-running specifications of the EM series discussed above are marketed as standard cylindrical roller bearings at NSK. We expect to introduce this product into other industrial uses, providing a real advantage for designers who need to reduce the noise emissions from their machines.

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* in Japanese

Takashi Murai

Development of the Super Wear-Resistant (SWR™) Bearing

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Corporate Research and Development Center

ABSTRACT

Wear is a serious problem for rolling bearings that are used under extremely low rotation speed, due to insufficient formation of oil film. Self-aligning roller bearings used for continuous casting machines are a typical example of this application, which require longer life.

We have developed a high wear-resistant SWR™ bearing utilizing new materials and heat treatment technology. In addition to wear resistance, SWR™ bearings are superior in surface-originated fatigue life. Furthermore, SWR™ bearings are superior to conventional (SUJ2) bearings in core toughness, due to the case hardening heat treatment, which is used for this new material.

1. Introduction

Metal contact between the bearing ring and rolling element of rolling bearings is prevented when an oil film is formed over the contact surface during ordinary operating conditions. When the bearing is operated at an extremely low speed, formation of the oil film lessens due to the difficulty of drawing lubricant over the contact surface. The resulting metal-to-metal contact causes wear. A typical example is the spherical roller bearing used in the guide rolls of a continuous casting machine.

The spherical roller bearing for a continuous casting guide roll is operated at an extremely slow speed and suffers from insufficient lubrication further complicated by the entry of water, fine dust, and heavy wear due to high loads. These problems often result in breakage, requiring countermeasures.

Improvement of lubrication to reduce wear can be achieved by the use of oil-air lubrication. This method, however, is not practical due to the prohibitive cost of making modifications to existing equipment. The use of a cylindrical roller bearing with no differential slide would also prove effective, but this bearing is applicable only to one side of the roll since it cannot carry the axial load.

With this in mind, we developed a bearing, whose life has been extended by means of material and heat treatment technologies, and is also free of modifications to equipment, bearing type, or dimensions. This report introduces characteristics of our newly developed SWR™ bearing.

2. Development Concept

Understanding the damage mechanisms of a bearing is essential for extending bearing life. The bearing of a continuous casting guide roll is used for the rotation of the inner ring. Heavy damage is remarkable on the outer ring where the loading zone is fixed. Accordingly, the inner ring and rolling elements present no particular problem. Therefore, it is considered important to take an appropriate measure against damage to the outer ring. We have investigated the damage mechanism of the outer ring of a spherical bearing for a continuous casting guide roll.

Fig. 1 illustrates the damage mechanism. Note that the raceway of a spherical roller bearing is in two rows and that Fig. 1 shows only one of these rows. First, wear occurs due to differential slip and spin slip. The hatched portion in the figure is the worn portion. Two pure rolling points with zero slip exist on the contact surface between the bearing ring and rolling element. Since wear at these

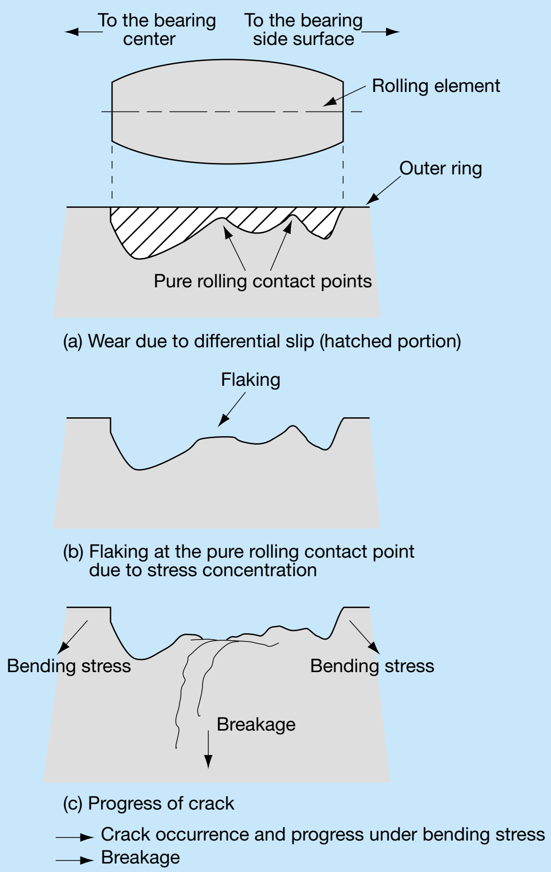


Fig. 1 Fracture mechanism of outer rings of spherical roller bearings used for continuous casting machines

points is small, these points appear to have two crest-like shapes. Then, pure rolling points with less wear develop flaking under concentrated stress with increased cracking. With the bending stress acting on the outer ring, flaking and cracking further extend the crack in a direction vertical to the raceway, eventually resulting in breakage.

Considering the above description, the following three items were chosen as the SWR™ bearing development concepts to enhance durability:

1) Development of new materials superior in wear resistance and optimization of heat treatment specifications.
2) Application of TF technology, namely, the life-extending technology unique to NSK, for improving surface originated type flaking life.
3) Improvement of the core toughness by use of case hardening technology. (Conventionally, the through hardened type steel, SUJ2, has been used.)

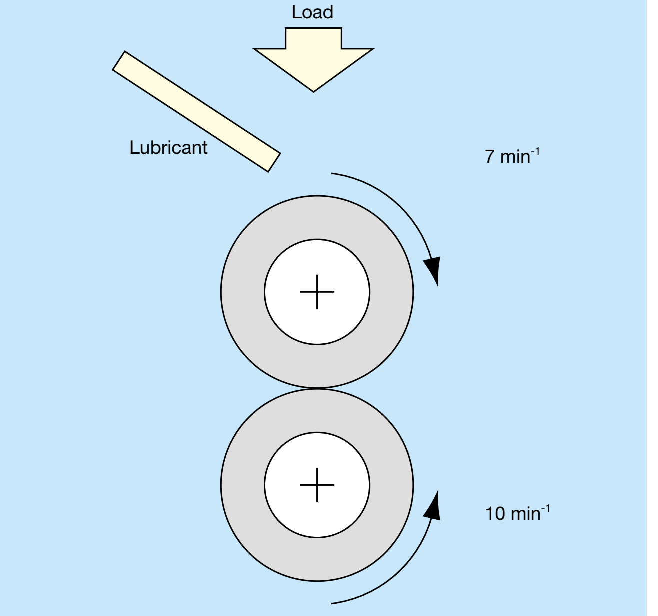


Fig. 2 Schematic of two-ring type wear tester

3. Characteristics of SWR™ Bearing Steel

After completing studies based on the above concepts, a new type of steel was developed. Characteristics of the newly developed steel are described below.

3.1 Wear resistance

3.1.1 Test method

The two-cylinder type wear tester was used for evaluation of wear resistance. Figure 2 shows the outline of the wear tester. A pair of ring-shaped test pieces (ø30 outside diameter × ø16 inside diameter × 7 mm width) was used in the test and the specified load was applied with peripheral surfaces in contact with the test pieces for the rotation test. The weight of the specimen was measured before and after the test, and the loss of weight was assumed to be the amount of wear for evaluation. Test conditions included a rotation speed of 10 min^{-1}, a slip ratio of 30%, contact pressure (P_{max}) of 880 MPa, and was conducted for 20 hours while supplying lubricant at a rate of 2 ml/min.

Two lubrication tests were made. They were an oil lubrication test using spindle oil, and a water lubrication test using ion-exchanged water to check the effect of water on wear.

3.1.2 Result of the oil lubrication wear test

Fig. 3 shows the results of the oil lubrication test. The left and right bars represent the amount of wear for each of the upper and lower test pieces (Fig. 2), respectively. For the test that incorporated our newly developed steels in mutual contact, the amount of wear was about 1/7 of that of conventional steels (SUJ2). In other words, the wear resistance of the newly developed steel is about seven times that of conventional steels. Based on the test results

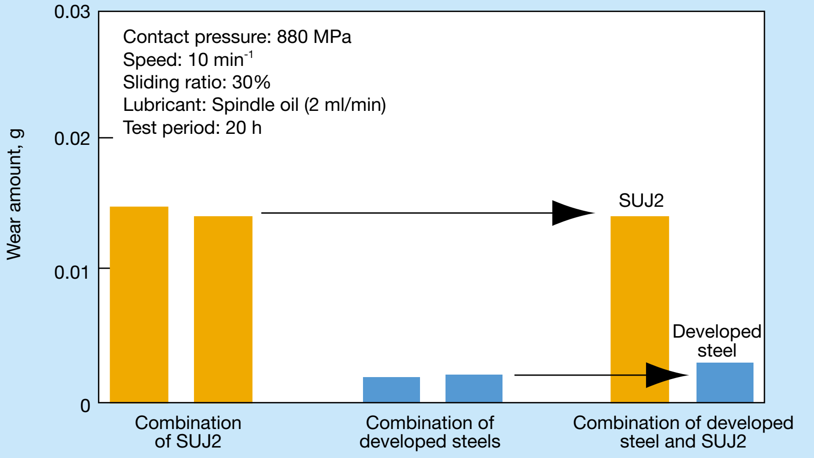
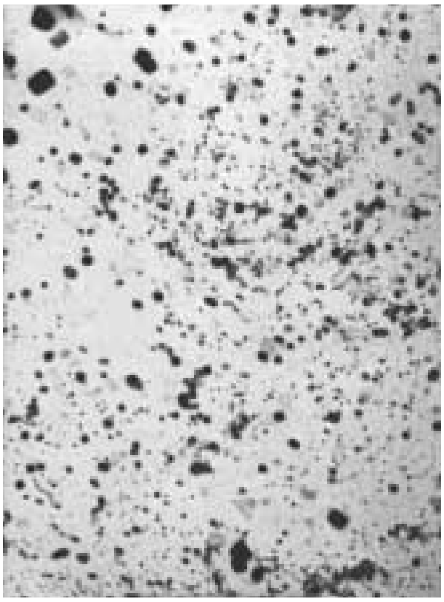


Fig. 3 Result of oil lubrication wear test


(a) Developed steel

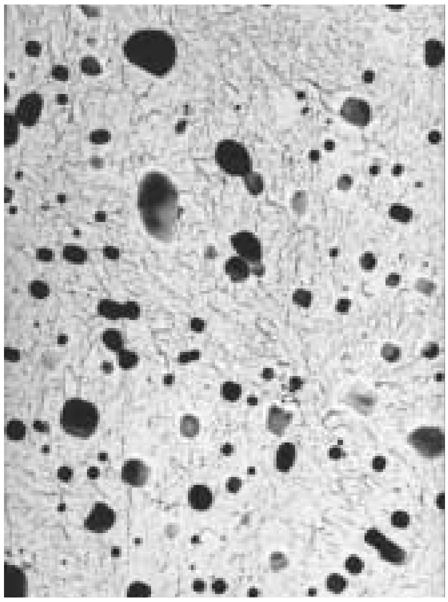

(b) SUJ2

Photo 1 TEM photograph of precipitates by extraction replica method

using a combination of newly developed and conventional steels, the newly developed steel, which is superior in wear resistance, does not increase wear of the conventional steel. It is also evident that the wear resistance of the newly developed steel is not affected by conventional steel.

Such superior wear resistance is achieved through precipitation of a large amount of extremely hard fine carbo-nitride. Photo 1 shows the result of a transmission electron microscope (TEM) observation of carbo-nitride of the newly developed steel and carbide of conventional steel (SUJ2) according to the extraction replica method. When compared with the carbide of conventional steel, carbo-nitride of the newly developed steel is known to be extremely fine. Precipitation of a large amount of extremely hard fine carbo-nitride could be achieved successfully through full exploitation of the carbonitriding technology that NSK has applied to rolling bearings, which is a world-first.

3.1.3 Result of the water lubrication wear test

Fig. 4 shows the wear test results of using ion-exchanged water for the combination of conventional steels and that of the newly developed steels. The wear amount is almost equal for both combinations, but about two times more than the combination of conventional steels in the oil lubrication wear test. The test result indicates that the entry of a large amount of water in the bearing may possibly fail in obtaining sufficient wear resistance from the newly developed steel. Accordingly, the test was made with a combination of developed and conventional steels. Results show that the wear of conventional steel was larger than a combination of conventional steels, but that the wear of the newly developed steel was much less. This result indicates that a material combination is of extreme importance when the entry of water is expected. As for the bearing of a continuous casting guide roll, we estimate that the

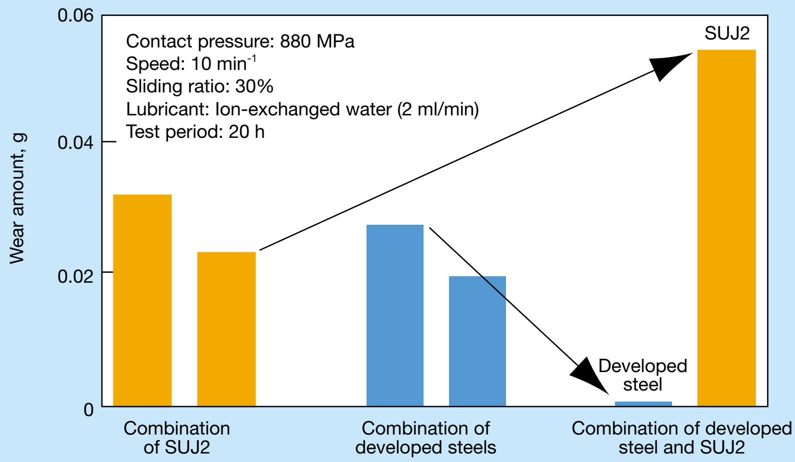


Fig. 4 Result of water lubrication wear test

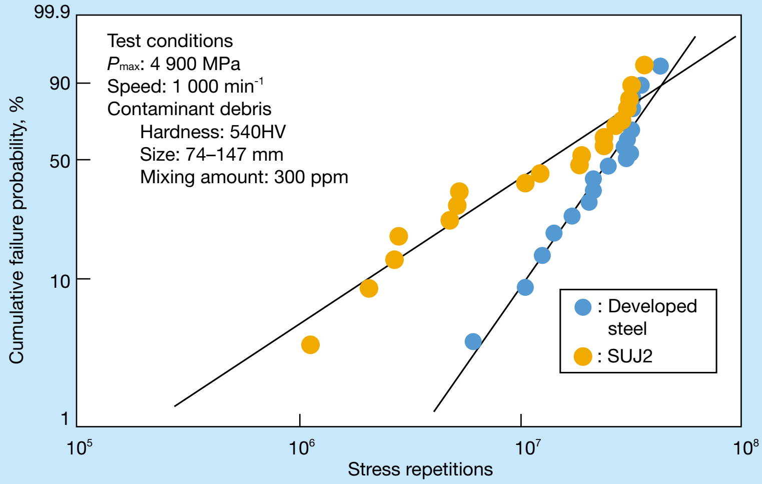


Fig. 5 Result of fatigue life test under debris contaminated lubrication

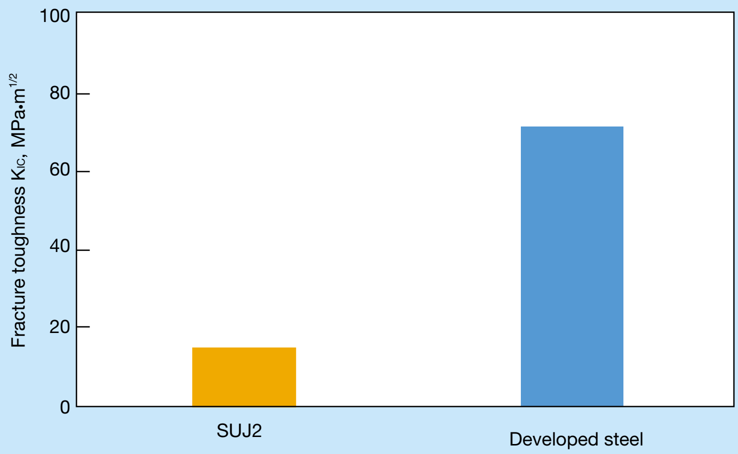


Fig. 6 Core toughness

bearing, as a whole, has superior wear resistance when the newly developed steel is used for the outer ring and conventional steel is used for the rolling element. As for the rolling element, almost no wear has been observed because multiple elements carry the load, which also causes distribution of wear increase due to the entry of water, thus avoiding substantial damage.

3.2 Surface originated flaking life characteristics

Under debris contaminated lubrication conditions, surface originated flaking occurs due to dents in the bearing raceway or metal contact due to faulty lubrication. NSK has proven for the first time in the world that an increase in the retained austenite amount is most effective for improving the surface originated flaking life characteristics under such severe lubrication conditions. Moreover, NSK has learned that this type of flaking characteristic is improved when the retained austenite amount is higher and the material is harder[2].

The newly developed steel is a product to which NSK's unique life extension technology or TF technology, namely the technology to control the retained austenite amount to the optimum value, has been applied. In addition, the hardness is enhanced through precipitation of large amounts of fine carbo-nitride, ensuring superior life characteristics. Fig. 5 shows evaluation results of surface originated flaking characteristics under debris contaminated lubrication conditions using a thrust type life tester. When compared on the basis of the L_{10} life at which the cumulative damage probability becomes 10%, it can be said that the life of the newly developed steel is about five times longer than that of conventional steel.

3.3 Core toughness

Fig. 6 shows the fracture toughness of the core. The newly developed steel, to which special alloy elements are added, is case-hardened so that its core toughness (K_{IC}) is about five times as high as that of a SUJ2 of a through hardened type. This also indicates a high resistance against fissures such as flaking and breakage. Case hardening is considered to allow the compressive residual stress in the surface layer to function effectively for prevention of breakage.

4. Result of Simulation Test with a Continuous Casting Machine

The durability test was made under conditions of extremely low speed and the entry of water into the bearing to simulate a continuous casting machine. A spherical roller bearing, 2210CD, with a bore of ø50, outside diameter of ø90, and width of 23 mm was used in the test. The test was made under conditions of a rotation speed of 4 min^{-1} and a load of 0.3 Cr. The durability test continued for 336 hours while circulating ion-exchanged water at 80°C within the housing and a steady supply of steam to the inside of the bearing. See Fig. 7.

Fig. 8 shows the cross-section profile of the outer ring raceway at the maximum loading position after the test. The hatched portion in the figure is a worn portion. When compared in terms of the maximum wear depth, the wear amount of the SWR™ bearing is about 1/3 of that of conventional bearings. Based on this test result, wear resistance of an SWR™ bearing is about three times greater than a conventional bearing. When the wear amount is compared by means of the area of hatched portions, the wear amount of an SWR™ bearing is about 1/7 of that of a conventional bearing. The rolling element was also measured, and the cross-section profile indicated no wear. The grease sampled from inside the bearing after the test was analyzed, and showed an extremely high water content of 12% compared to an average of 2% for a conventional bearing. This fact means that the SWR™ bearing demonstrates superior wear resistance regardless of severe lubrication conditions.

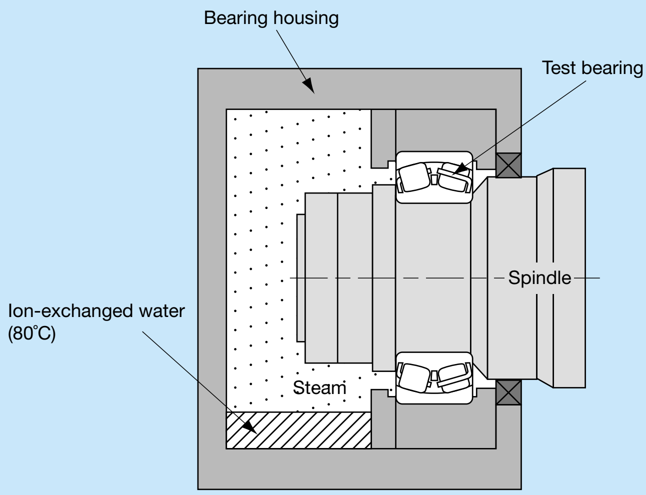


Fig. 7 Schematic of a continuous casting machine simulation tester

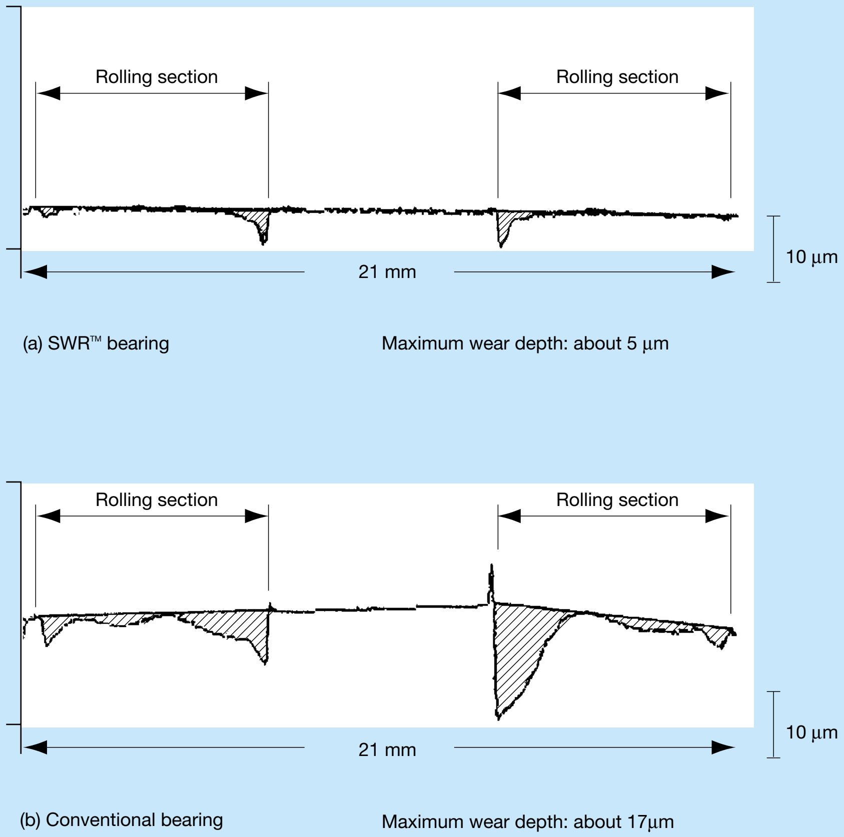


Fig. 8 Cross-section profile of the outer ring raceway after test (Maximum loaded region)

5. Conclusion

Developments have been made to extend life through material and heat treatment technologies for rolling bearings in which wear is a problem, specifically, the spherical roller bearing for the continuous casting machine. Our SWR™ bearing has proven to be superior not only in wear resistance, but also in surface originated flaking life characteristics and core toughness. Field tests also showed satisfactory results. We plan to further develop the application of this bearing in the field in which wear is a problem, in addition to developing continuous-casting machine applications.

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*in Japanese

Kenji Yamamura

Manabu Oohori

Pressed Rocker Arm

Satoshi Kadokawa
Bearing Technology Center

ABSTRACT

The worldwide market for end pivot-type rocker arms expanded greatly while, at the same time, customers requested significant cost reductions on components for engine valve trains. As a result, the development of pressed rocker arm assemblies became an important requirement. In response, we first set down the following development objectives:

1. Cost competitiveness
2. High strength and rigidity
3. Reduced inertial mass (compared to conventional pressed rocker arms)

We then developed pressed rocker arms that met these objectives. This report introduces the key features and characteristics of NSK's new pressed rocker arms.

1. Introduction

The environment surrounding valve train systems of automobile engines has changed remarkably. Starting with the application of a light alloy for center pivot type rocker arms, various developments have been made for greater efficiency and output, such as the use of roller rocker arms, and the transition from multistage cam-changing to continuously variable cam-phasing of various VVT or VVL systems. In line with this trend, press forming of the rocker arm has been promoted in an effort to minimize the number of parts, thus lowering costs. Hence, NSK has developed a pressed rocker arm based on its unique technologies. An outline and performance of this rocker arm is described in this report.

2. Development Concept

Considering the drawbacks of conventional rocker arms, the concept of this development is to offer a product that utilizes superior manufacturing and product technology. Specifically:

(1) Cost reduction through press forming; from one plate, and no welding
(2) Rigidity and strength equivalent to die cast products
(3) Lessening of the inertial mass from that of conventional pressed rocker arms

End pivot type (rocker arm) shown in Fig. 1 was chosen as the target product for development.

3. Problems with Conventional Technologies

Traditional casting of rocker arms offers the manufacturer great flexibility in thickness and design. The biggest challenge facing the press forming process is maintaining the same level of strength and rigidity of a cast rocker arm.

An analytical model with a material thickness of T = 3.2 mm (Fig. 2) was manufactured using the most common design of a press rocker arm with a U-shape vertical section. Fig. 3 illustrates the distribution of component stress for a rocker arm under load. We confirmed that that the fracture points and the maximum component stress

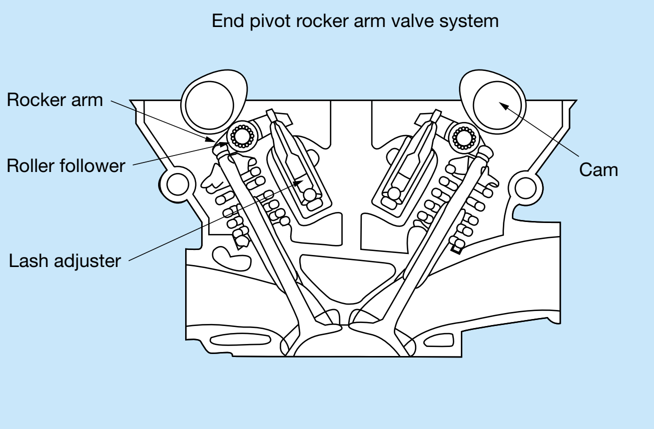

Fig. 1 Valve-train system (End pivot type rocker arm)[1)]

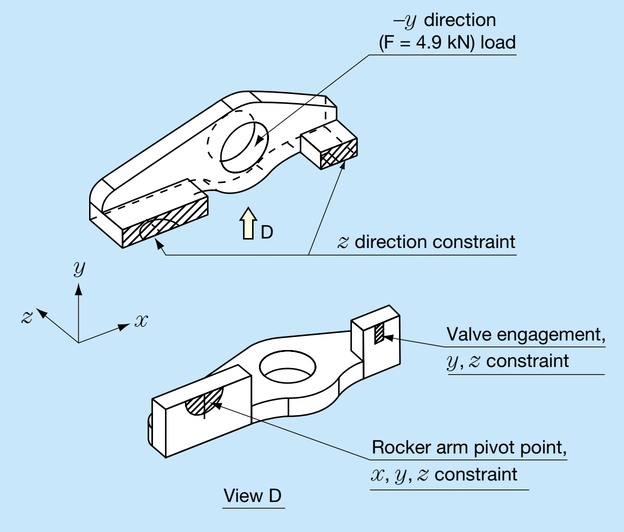

Fig. 2 Boundary condition of FEM analysis

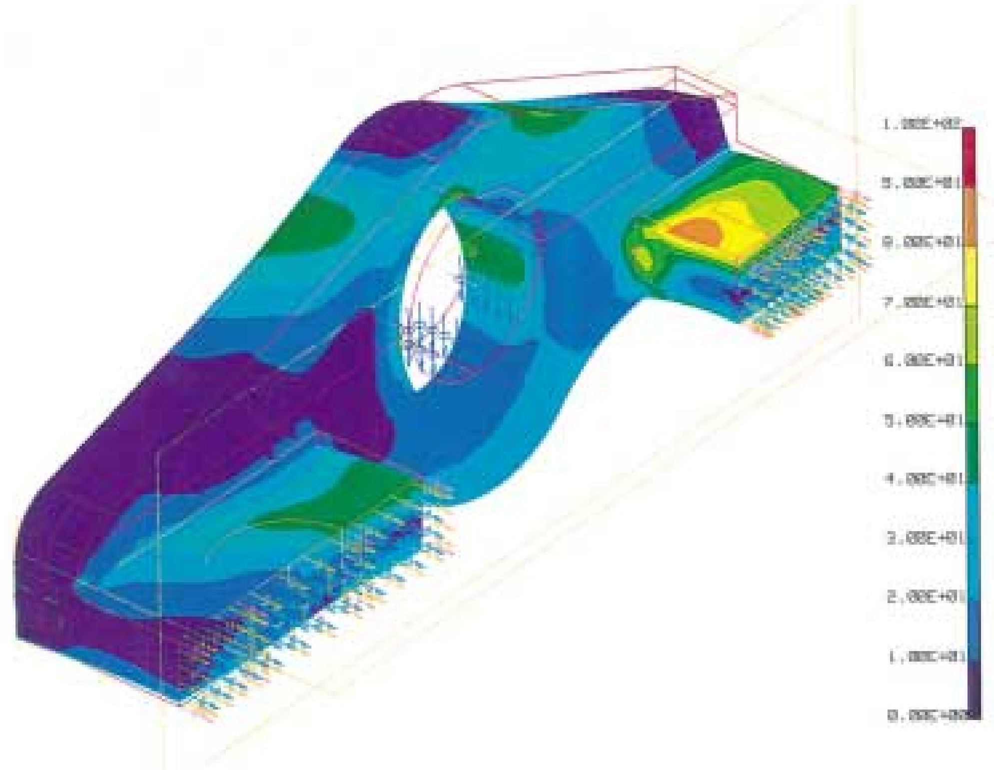

Fig. 3 Component stress distribution of a conventional model

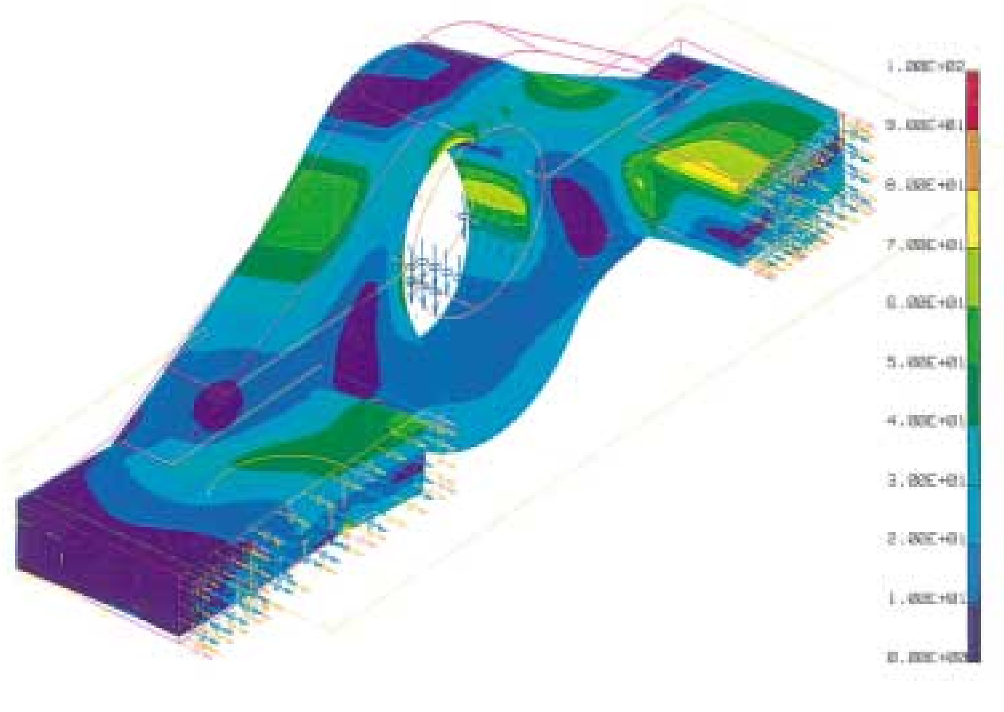

Fig. 4 Component stress distribution of a simple developed model

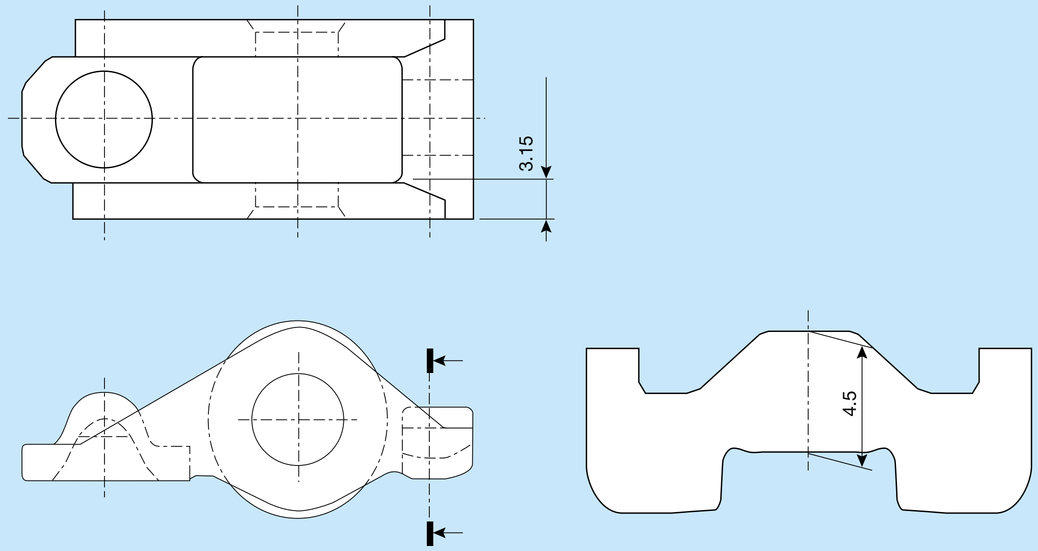

Fig. 5 Features of frame shape

locations coincided with each other. Conventionally, a certain portion of the rocker arm sidewall was considered necessary to increase rigidity. However, the component stress distribution diagram shows that component stress generation here was limited and that a certain portion of the sidewall could be eliminated without affecting the inertial mass required from a valve train system.

Consequently, the rocker arm was contoured in places where component stress was small, and the size of thickness was increased where the component stress was high (T = 3.2 mm to T = 4.0 mm). The component stress distribution diagram of the modified model shows component stress being distributed evenly over the whole area of the rocker arm, thus achieving a satisfactory balance (Fig. 4).

4. Construction and Features

4.1 Features regarding shape

NSK's newly developed pressed rocker arm has the following features:

(1) Less component stress by increasing the thickness of valve engagement relative to the size of sidewall thickness (Fig. 5)
Increased thickness ratio (Size of increased thickness/Size of sidewall thickness) = 1.2 to 1.6

(2) Less inertial mass by contouring sidewalls of rocker arm pivot point

4.2 Features regarding manufacturing

NSK has increased the thickness of valve engagement to enhance strength. The original purpose of press forming is

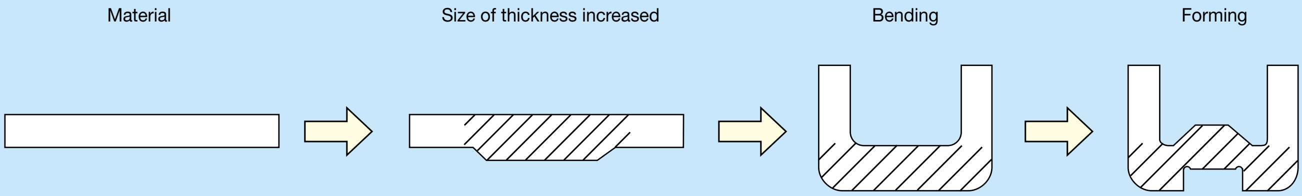

Fig. 6 Manufacturing process

to reduce costs. Therefore, we developed a method that allows the manufacturing of a rocker arm from a single plate. Fig. 6 illustrates the overall process of first increasing the size of thickness of the base material (similar to cold forging), followed by bending and forming. If hardening of the material becomes excessive, annealing is performed halfway through the process.

As described thus far, strength of the NSK pressed rocker arm is enhanced by increasing the size of thickness for the weakest portion of the part (a phenomena of pressed parts). Inertial mass has been reduced by selective contouring of sidewalls of the rocker arm pivot point. The performance of our newly developed product (Fig. 7) is described below.

Fig. 7 Appearance of developed rocker arm

5. Performance

5.1 Inertial mass

One feature of our newly developed product is the reduction of inertial mass by selective contouring of sidewalls of the rocker arm. Any weight gain caused by a size of thickness increase is offset by contouring certain portions of the rocker arm, so that the total weight is lower. By contouring, the inertial mass can be reduced by about 8%. Fig. 8 shows three-dimensional models utilized for calculating the inertial mass. Weight has also been reduced by 7 to 8%, which is lighter than conventional rocker arms manufactured with the casting process.

5.2 Static strength

Criteria for static strength include meeting certain requirements for rigidity, and breaking and impact resistance. The values below show that our newly developed rocker arm enjoys sufficient static strength:

(1) Rigidity: more than 65 kN/mm

(2) Break resistance: more than 20 kN

(3) Impact resistance: more than 19.6 kN × m

Test results confirm the strength and impact resistance of the NSK pressed rocker arm to be equivalent to conventional cast products (Fig. 9).

Normal rocker arm model with sidewalls

NSK pressed rocker arm model with contoured sidewalls

Fig. 8 3D model

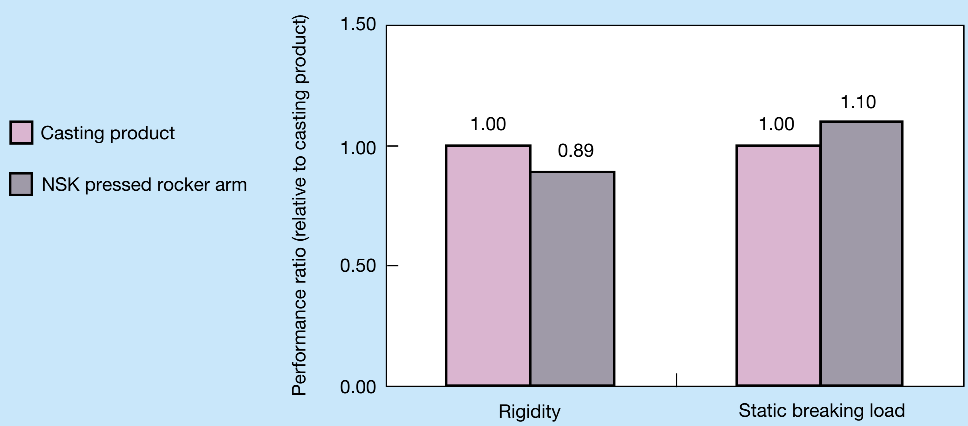

Fig. 9 Test result of rigidity and static breaking

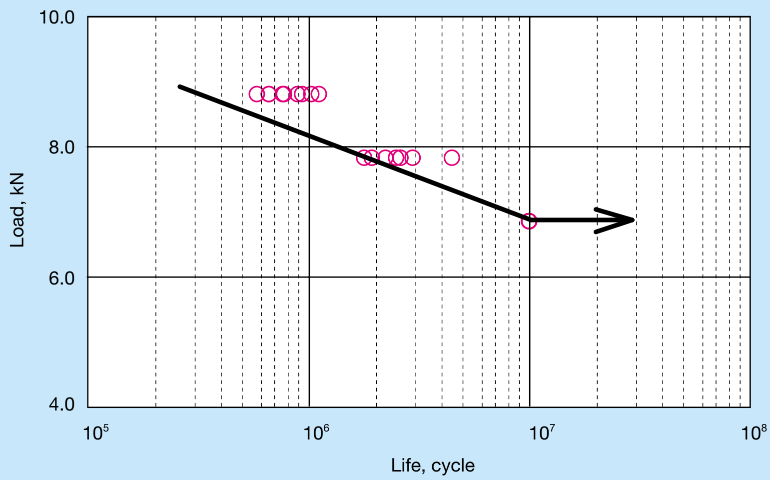

Fig. 10 Fatigue test results

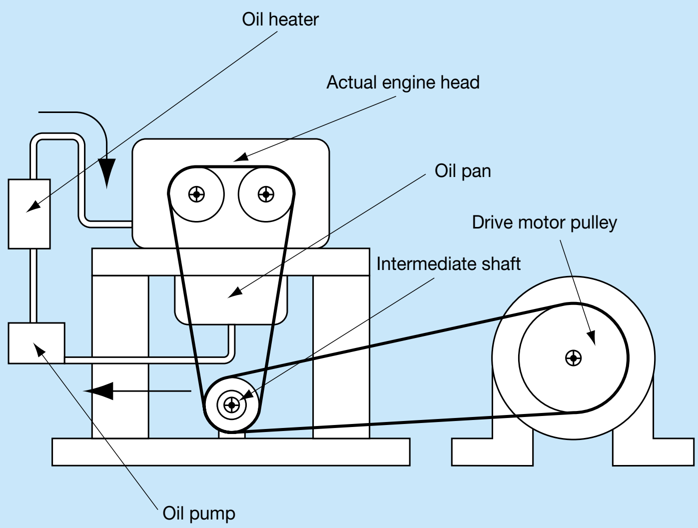

Fig. 11 Scheme of the test machine

5.3 Fatigue strength

Fatigue strength is more critical for the actuating lever of the rocker arm than static strength. In particular, the bending and forming of press materials tend to cause cracking and creasing while the increase in size of thickness causes component stress. Accordingly, contouring or annealing is utilized to minimize any weakening of the material.

Fig. 10 shows the actual fatigue strength as 1×10^7 cycle or more under a load of 6.86 kN or less.

5.4 Durability

The rigidity test (Fig. 9) is for the evaluation of basic strengths. The test cannot determine wear and effects of sliding parts on the bearing under actual operating conditions in an engine or dislodgment of the rocker arm during excessively high speed rotations. Therefore, these specific parameters were evaluated by means of a test machine in which the actual engine head assembly is driven with a motor (Fig. 11).

Test conditions

- Name: High-speed durability test
- Speed: Engine rated speed
- Lubrication: Engine oil
- Oil temperature: 120°C
- Test period: 400 hours

Test results

(1) No abnormalities (crack, fissure, etc.) were observed for the rocker arm

(2) No abnormal wear was observed in the bearing, valve, pivot point, and other sliding parts

(3) No dislodgment of rocker arm

All of the tested items performed well in terms of durability, and remained free of any abnormalities or problems.

6. Conclusions

Originating from North America, the pressed rocker arm has come to Japan and is gaining popularity. NSK's developed rocker arm offers Japanese automobile manufacturers a product of superior performance for severe operating conditions that also overcomes the challenges of strength and durability.

We will continue to develop the pressed rocker arm to further reduce costs, increase number of product applications, while improving upon quality and performance. We would like to express our gratitude to Mitsubishi Motors for their cooperation during development.

Reference:

1) Engine Service Manual, Mitsubishi Motors Incorporation

Satoshi Kadokawa

Development of Double-Row Bearings for Automatic Transaxles

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ABSTRACT

The performance level of automatic transmissions and transaxles is evolving with the introduction of new technologies for the purpose of improving transmission efficiency.

At the present time, manufacturers are developing new types of automatic transmissions and transaxles and putting them on the market. These units have adopted designs that incorporate many types of double row tapered roller bearings.

This paper will discuss the important role that these bearings play in achieving a lightweight design and greater fuel efficiency.

1. Introduction

Up until 2000, the share of cars equipped with an automatic transmission in Japan exceeded 90%. The performance of Japanese automatic transmissions is currently at the highest level in the world. In tune with the growing awareness of the importance of global environmental protection in recent years, automatic transmissions have been required to be lighter and more efficient. New technologies have been introduced to meet such requirements, and have further enhanced transmission performance, such as downsizing, low-speed lockup, neutral control, and continuously variable speed control with CVTs.

Automobile and automotive component manufacturers have introduced these new technologies into their products. Especially in automatic transmissions for front engine, front-wheel drive drivetrains (FF A/T) that offer sequential shift control, and for the reduction of gear support for which various types of double-row bearings have been utilized. The following sections will discuss the role of double-row bearings in regards to weight reduction and efficiency improvement of an FF A/T.

2. Changes in Support Structure

Bearings for conventional A/Ts and new-type A/Ts provide support to the gears in a different manner (See Fig. 1). For example, in conventional type A/Ts, bearings provide support to both ends of the output gear, while bearings in newer A/Ts provide cantilever support. With an input shaft running through the bore of the bearing, and with an automatic speed-change clutch assembly and a planetary gear set at both ends of the gear, the A/T can vary speed in four steps. This structure has been adopted by Japanese manufacturers, with nearly half of all FF A/Ts produced in Japan having this structure. The use of a double-row bearings increases the flexibility of a design of a circumference structure, and actually results in a 5-mm reduction in overall length and 5-kg weight reduction of some FF A/T models.

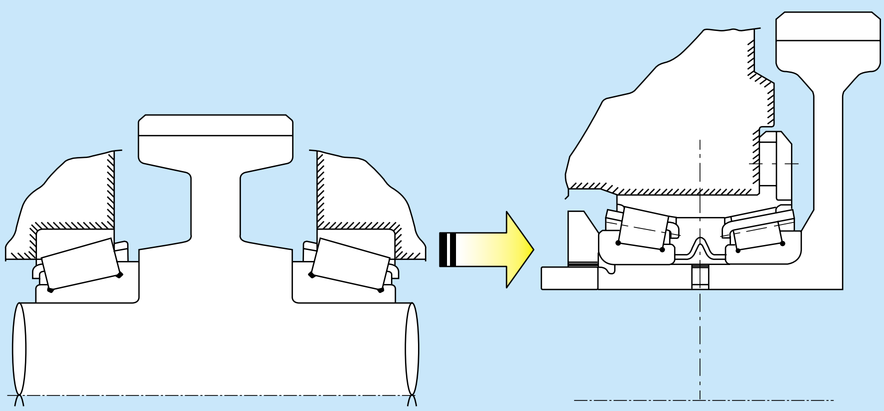


Fig. 1 Change in configuration for supporting gears

Photo 1 Double-row bearing for A/T

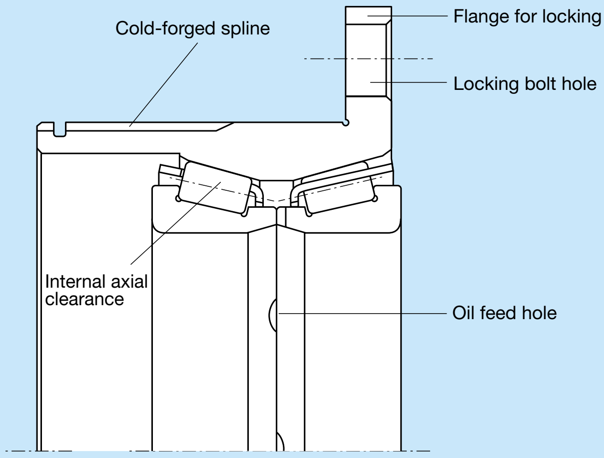


Fig. 2 Schematic of double-row bearing for A/T

3. Various Shapes of Bearings

As for FF A/Ts, bearings with a more complicated shape than those of standard bearings are used, because their shape reflects a design that is more suitable for structurally complicated component parts, as well as meeting axial space restrictions, and functional requirements. NSK produces a variety of bearings for FF A/Ts (See Photo 1 and Fig. 2). Photo 1 shows a double-row bearing with an outer ring that has a flange with bolt holes for mounting. The opposite side is splined for mounting a one-way clutch. This bearing also has a preset axial clearance for a smooth fit with the shaft and case, therefore a specified preload can obtain by tightening the axial nut in the preset torque range. This design simplifies the assembly process and prevents excessive preloading and torque loss.

4. Bearing Downsizing

Double-row bearings used by automobile manufacturers for FF A/Ts are of special dimensions, and are not generally comparable to other bearings because of the differences in engines and speed change conditions in which the bearings are operated. Fig. 3 compares basic load ratings of A/T output shaft bearings in a two-liter class car. The bearings used by Companies D and E in Fig. 3 are manufactured with NSK long-life material heat treatment (Hi-TF) specifications, Hi-TF bearings have a longer rolling life, a lower load rating, and consequently, a smaller size than normal bearings. If the Hi-TF bearing used by Company D in Fig. 3 were made of a standard material, such as AISI 52100, the size of the bearing would be larger, such

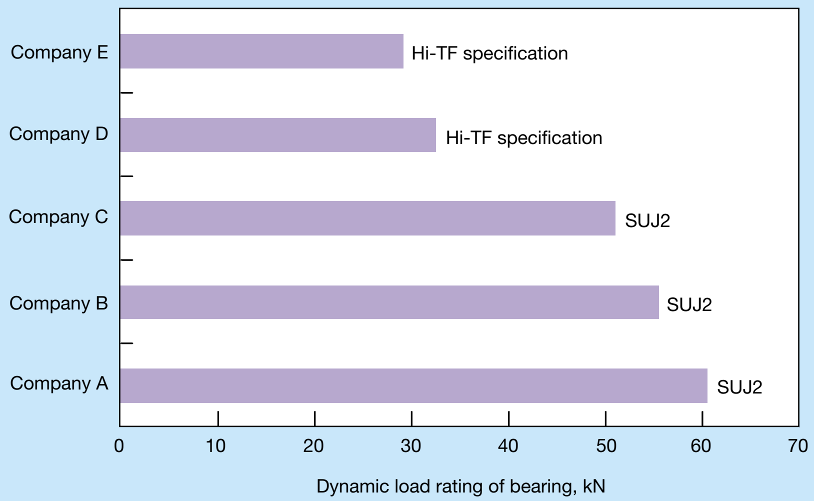


Fig. 3 Basic dynamic load ratings

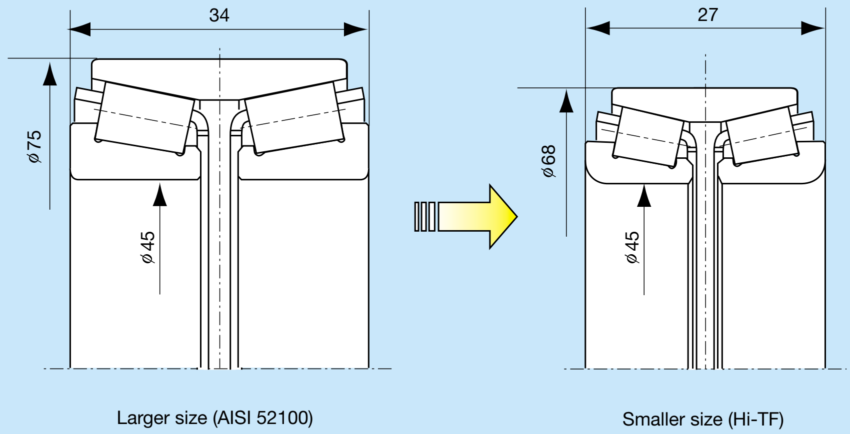


Fig. 4 Reduction of bearing size

as shown in Fig. 4. Compared to AISI 52100, Hi-TF bearings are approximately 35% lighter, and have a 10% smaller outside diameter. Thus, these bearings, contribute to the downsizing of applicable parts.

5. Changes in Bearing Fixing Structure

Bearings for transmissions used to be designed on the assumption that disassembly and replacement could be performed, consequently to fix a double-row bearing in place, a flange or snap rings have mostly been used. To reduce the weight of an A/T, shortening its overall length is important. Therefore improvement of the bearing assembly structure is required. One method used to improve the bearing fixing features a structure in which, once the bearing is assembled in the transmission case, the bearing cannot be disassembled (See Fig. 5). When the bearing is press-fitted into a transmission case, as shown in the example, the snap ring contracts towards the inside of the bearing, and expands towards the outside of the bearings when it reaches the groove, and fixes the bearing into position. If the bearing is damaged, not only the bearing but the transmission case must be replaced, having a dramatic effect on cost. In view of such risk, this bearing fixing structure is used only when bearing failure is highly unlikely. The combination of highly reliable bearings and this bearing fixing structure has been proven successful in reducing bearing width, housing length, and overall A/T length.

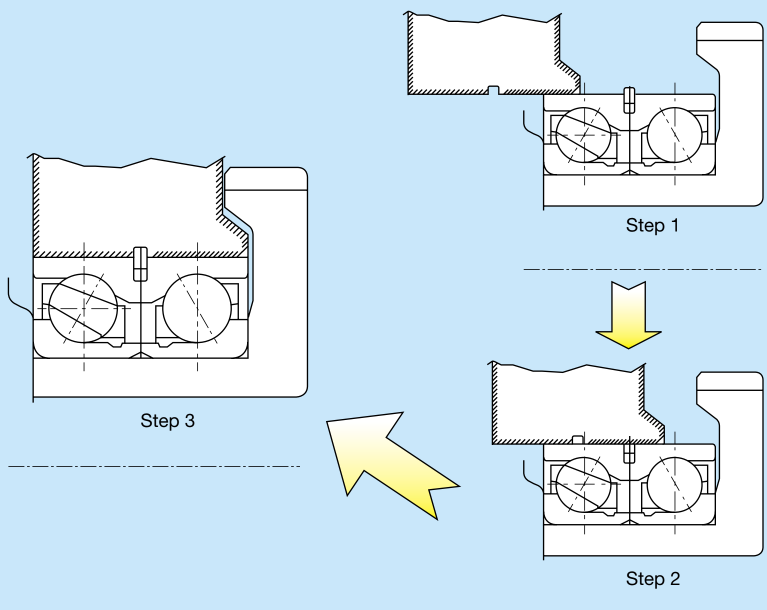


Fig. 5 Improved fixing method

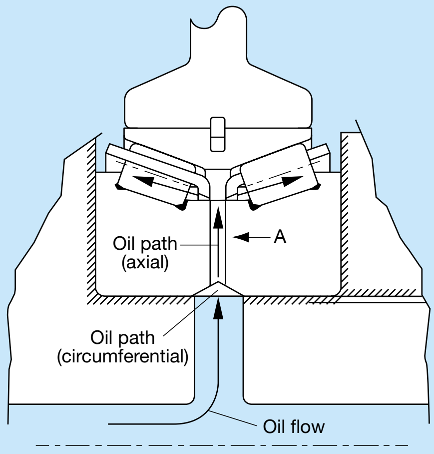


Fig. 6 Oil lubrication

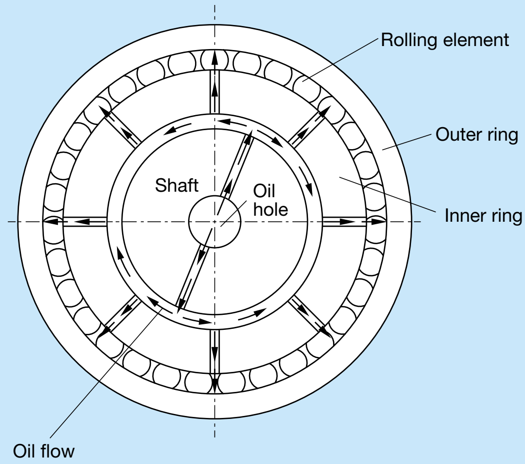


Fig. 7 Oil flow of bearing interior (View A in Fig. 6)

6. Overdrive Bearings

In an A/T that has an overdrive by sub-reduction stage on the second shaft, input power from the first shaft is transmitted to the gear of the second shaft, and then transmitted further by the planetary gear set. In this structure, a double-row bearing is used as an idler bearing in the driven gear of the second shaft. A special feature of this structure is that both the outer and the inner rings of the bearing are synchronously rotated while the A/T is in overdrive. When the vehicle is running at a high speed in overdrive mode, the bearing is continuously under static load by constant gear reactions, and fretting tends to occur on the rolling contact surfaces of the rolling elements of the bearing, and may develop into early flaking and noise. Lubrication of the bearing with an increased oil flow rate can prevent this fretting. If the bearing is a double-row bearing, an oil path is formed on its inside diameter as shown in Fig. 6. Oil is evenly dispersed through the oil grooves in the inner ring to the entire raceway surface (See Fig. 7). This arrangement is used to successfully ensure the increase of bearing reliability and maintenance-free bearing operation.

7. Bearing Torque Reduction

For tapered roller bearings, whose torque during operation is generally considered high, reducing the contact length of the rolling elements can achieve lower torque as well—low torque is an essential design for A/Ts that seek to improve efficiency.

8. Conclusion

A/T bearing design has evolved from simple to complex, which reflects the various requirements for today's bearings. The evolution has always been focused on the reduction of size and weight, based on material and heat treatment improvements, optimization for lower torque, and the utilization of analysis technologies. The effect of these evolutions on bearings in terms of improved automotive fuel efficiency per bearing is very small, but because many bearings are used in an A/T, the sum of their improvements is significant. This article has presented a few of the effects of using double-row bearings for A/Ts, we will continue to pursue further advancement into the development of bearings for A/Ts and related technologies.

Yoshitaka Hayashi

Development of Low-Noise NSA Grease for Fan Motor Bearings

Youichirou Sugimori
Corporate Research and Development Center

ABSTRACT

IT related devices and household appliances have a deep impact on the comfort of the home. This places a strong demand on manufacturers to create products that are in concert with a quiet environment.

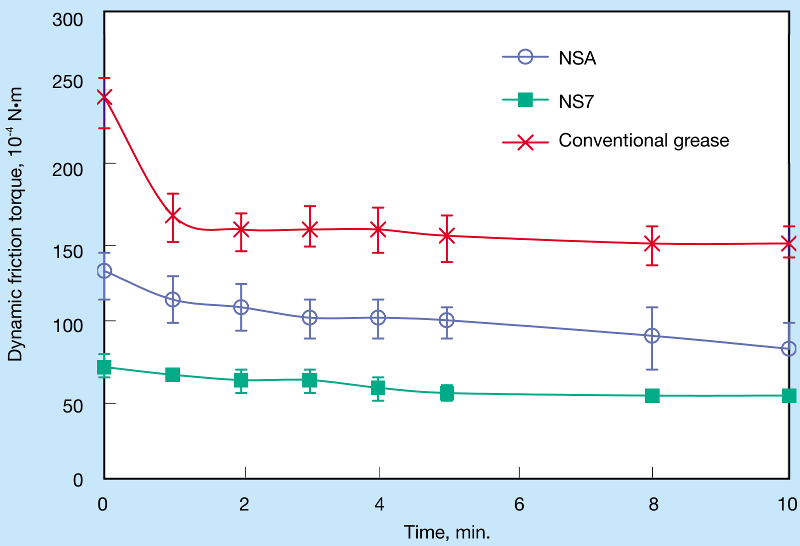
Until now, such products were able to meet sound performance and low friction torque requirements using two NSK greases: NS7 and NSC. These two brands of grease have been used in abundance with motor applications since their initial development. However, recent market trends have demanded higher standards of grease. Grease must now be compatible with a wider range of temperatures, have greater sound durability performance, and be employable under more compact operating conditions while supporting higher motor efficiency.

In light of higher standards and environmental concerns, NSK developed NSA grease in 2000. This grease is superior to NS7 and NSC in a variety of ways, including sound durability performance at high temperatures. Durability has also been improved in response to the increase of motor production in China where local conditions demand greater fretting resistance.

1. Introduction

Along with the rise of living standards in recent years, people are seeking greater comfort in their daily lives. This includes the use of computers, appliances, and other modern conveniences at work and at home. However, these conveniences create small sounds that are regarded as a source of noise. IT related equipment and household appliances such as air conditioners, vacuum cleaners, washing machines, and cooking range hood ventilators all incorporate deep-groove ball bearings (4 to 15 mm bore diameters) into their design. These bearings produce a very small vibration as they rotate, resulting in audible sound. Such bearings are now required to have low-noise and low-vibration performance[1).

In 1975, NSK developed lithium soap grease NS7, and then in 1988, developed lithium soap grease NSC. Both products are mainly comprised of ester-based synthetic oil, specifically designed for bearings used in IT equipment and household appliances. Because of their low noise and



Test bearing
I.D.: 15 mm, O.D.: 35 mm, Width: 11 mm

Evaluation conditions
Running speed: 1 400 min^{-1}
Ambient temp.: Room temp. (20–25°C)
Axial load: 39.2 N
Number of measurements: 3 measurements for each grease
Amount of grease packed: 35% of inner capacity

Fig. 1 Dynamic friction torque measurements

Table 1 Typical properties of greases

		NSA	NS7	Conventional grease	Test method
Color		Light brown	Light brown	Yellowish brown	
Thickener		Lithium soap	Lithium soap	Lithium soap	
Base oil		Synthetic hydrocarbon oil and ester oil	Ester oil	Naphthenic mineral oil	
Kinematic viscosity, mm^2/s	40°C 100°C	115 15.2	26 5.1	140 10.5	ASTM D445
Worked penetration	25°C, 60W	311	250	277	ASTM D217
Dropping point °C		201	192	182	ASTM D566
Copper plate corrosion	100°C, 24h	Pass	Pass	Pass	ASTM D4048
Evaporation, mass %	99°C, 22h	0.30	0.30	0.32	ASTM D972
Oil separation, mass %	100°C, 24h	3.3	1.2	2.0	FED STD321
Oxidative stability, MPa	90°C, 100h	0.020	0.025	0.034	ASTM D942
Worked stability	25°C, 10^5W	337	306	305	FED STD313
Water washout, mass %	38°C, 1h	1.5	1.3	2.2	ASTM D1264
Low-temperature torque at -30°C, N·m	Starting Running	0.099 0.070	0.071 0.022	0.630 0.132 (-10°C)	ASTM D1478
Bearing corrosion prevention	52°C, 48h	#1	#1	#1	ASTM D 1743

low-friction torque performance, NS7 and NSC continue to be widely used in many bearings. In view of the sharp increase of fan motor bearings used in China, NSK developed its NSA grease in 2000. NSA grease features improved fretting resistance and high-temperature durability, in addition to quieter performance.

2. Fan Motor Production in China

Intense competition for cheaper household appliances, including air conditioner fan motors, is a growing trend in China. In part to lower production costs, the output of air conditioner fan motor production output has been sharply increasing. Chinese output for these products has now reached a level of 15 million units per year. This accounts for about 65 percent of the gross demand in the world[2]. China is becoming the fan motor supply center of the world. In some localities, however, rugged roads continue to be heavily used by trucks for long distances. Bearings in motors or air conditioners that are transported by these trucks may suffer from shock load and excessive vibrations, resulting in fretting of raceway surfaces, which may cause bearing noise.

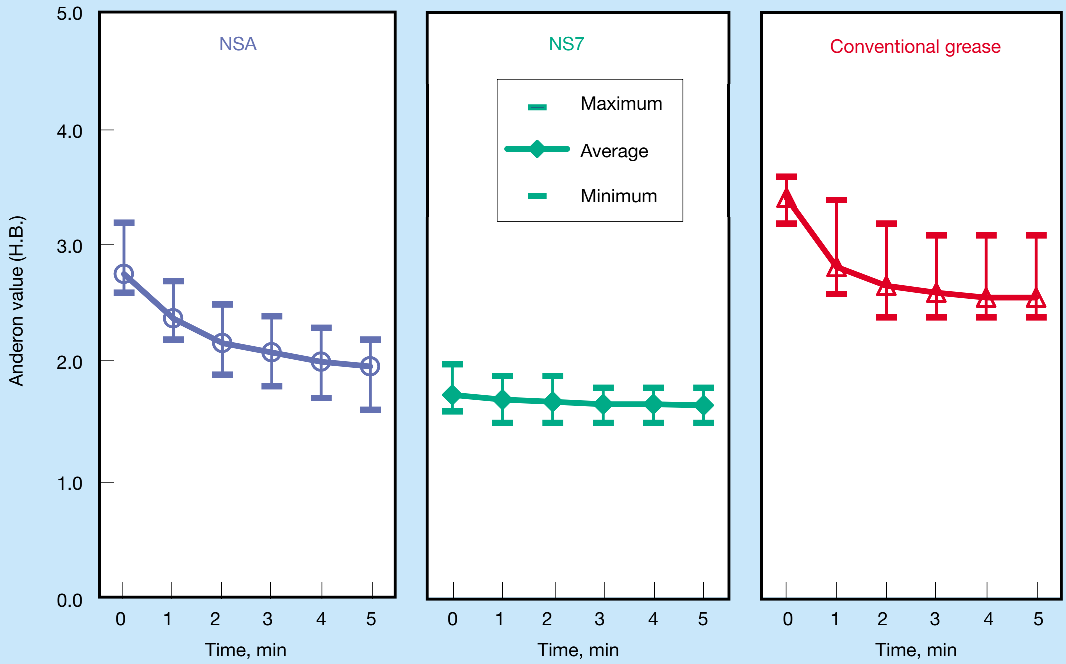
The acceptance inspection criteria of motor manufacturers for rolling bearings and the gross acceptance inspection criteria of air conditioner assembly plants for motors are very rigid in China compared to those in other countries. Bearing noise, even if otherwise inaudible under the dominating hum of a running fan, is often singled out for further evaluation in China. NSA grease is a bearing grease that can help bearings meet such exacting requirements.

3. Composition and Properties of NSA Grease

NSA grease is lithium soap grease based on a high-viscosity mixture of synthetic hydrocarbon oil and polyol ester oil (Table 1). This grease reduces frictional torque in spite of the high viscosity of its base oil. Fig. 1 helps illustrate the dynamic friction torque of NSA grease.

4. Initial Sound Performance

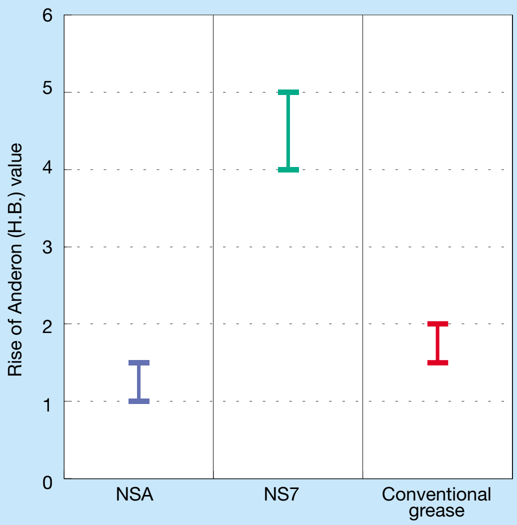
Noise levels (dB(A)) of rolling bearings are usually measured in a soundproof chamber. There is a direct relation between noise levels and vibration values (Anderon value). Anderon values are easily obtained by placing a vibration transducer in direct contact with the outer ring of a bearing. For this reason, Anderon value was measured and evaluated to determine the sound performance of NSA grease. Fig. 2 shows a comparison of test results for different grease products. NSA grease had better sound properties than conventional grease, and comparable performance with that of NS7 grease, which is also based on low-viscosity ester oil.



Test bearing
I.D.: 15 mm, O.D.: 35 mm, Width: 11 mm

Evaluation conditions
Running speed: 1 800 min^{-1}
Ambient temp.: Room temp. (20–25°C)
Axial load: 39.2N
Number of measurements: 10 measurements for each grease
Amount of grease packed: 35% of inner capacity

Fig. 2 Initial sound measurements



Test bearing
I.D.: 15 mm, O.D.: 35 mm, Width: 11 mm

Evaluation conditions
Frequency: 50 Hz
Ambient temp.: 40°C
Axial load: 20–1 500 N
Number of vibrations: 90×10^5
Amount of grease packed: 35% of inner capacity

Fig. 3 Fretting wear test result

5. Anti-fretting Performance

Fig. 3 illustrates fretting resistance qualities for compared grease products. NSA grease outperformed NS7 grease in a long-term oscillating test under an atmospheric temperature of 40°C, corresponding to the hottest of summers where fan motors might be put to use. Its anti-fretting performance was also better than that of conventionally used general-purpose grease.

6. Sound Minimizing Performance

Fig. 4 shows the evaluation results of the sound minimizing performance of NSA grease.

Fan motor bearings packed with NSA grease and NS7 grease were operated in a thermostatic bath at 105°C while motor noise levels were measured at certain intervals. Although both motors produced increasing noise over time, the motor with NSA grease proved to be much quieter than the other motor, even after a year of continuous operation.

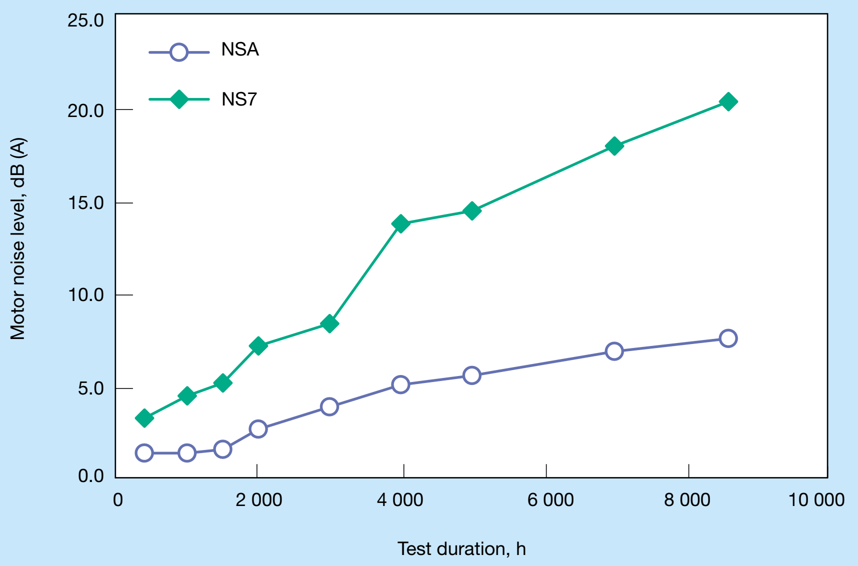


Fig. 4 Motor sound test result

7. Conclusion

The NSA grease is an environment-friendly grease, capable of providing low-noise bearings as described above. This grease has been increasingly used in the rolling bearings of fan motors of air conditioners currently produced in China for household use.

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*in Japanese

Youichirou Sugimori

Development of HTF Series Ball Screws for High Load Drive Application

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Precision Machinery & Parts Strategic Division

ABSTRACT

Recently, cries for environment conservation and effective use of energy have been rising sharply and the situation has resulted in a strong demand on the environment-conscious machine. Plastic injection molding machine is a typical example to fulfill such requirements. Replacement of hydraulic cylinder drives with electro-servo drives for the plastic injection molding machine is progressing rapidly because power consumption of the electro-servo drives system is 3 to 4 times better than the conventional driving system and also it ensures cleaner working environment and less pollution.

A ball screw used for electro-servo driven plastic injection machine requires ever-highest load carrying capacity and durability. For this reason, NSK Ltd. has developed and marketed "HTF Series," a specialized ball screw series for such heavy load applications.

"HTF Series" ball screw has come to a reality by providing a prolonged operation due to a design of equalizing load distribution to balls by optimum position arrangement of ball return tubes and a special internal design to sustain heavy load. In addition to it, we have investigated and confirmed an effect on installation of ball retaining pieces to "HTF Series" ball screws for further improvement in durability under extremely heavy load.

1. Introduction

Along with the expansion and diversification of ball screw applications in recent years, there is a strong demand for ball screws that have greater functionality for a wider number of applications, such as with all-electric high-load linear motion mechanisms. Here, the high mechanical efficiency and high power transmission capability of ball screws are utilized to replace conventionally hydraulic drives with new combination drives of ball screws and servomotors. Greater awareness of the environment and a stronger demand for energy efficiency have resulted in a push for machinery and equipment that are eco-friendly, and have encouraged the conversion from hydraulic to electro-servo drives on a global scale.

2. Electric Injection Molding Machines

2.1 All-electric & clean-running injection molding machines

In addition to various high-load applications of recent years, ball screws have been increasingly used in all-electric injection molding machines. In the past, these machines were mostly hydraulically powered, but with the development of clean-running all-electric machines, increasing numbers of Japanese companies are making the switch.

The main advantages of all-electric injection molding machines include:

(1) Energy Savings
Compared with hydraulically powered injection molding machines, which consume energy even in an

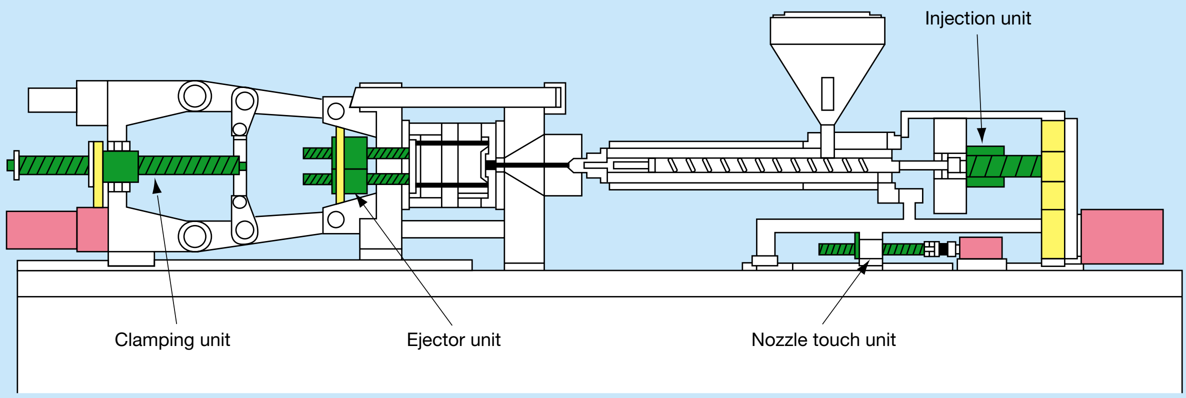

Fig. 1 Ball screws in electric injection molding machine

Photo 1 HTF Series ball screws

idle state, all-electric machines use energy only when motion is called for, thus significantly reducing power consumption by 70–75%.

(2) Pursuant to ISO 14001 Standards for Environmental Management Systems
Electric molders assure a cleaner working environment, promote environmental conservation by reducing hazardous fluids and by increasing energy savings.

(3) Maintenance-Free
Maintenance-free, because no hydraulic oil is used. In addition, water consumption for cooling is reduced approximately 70%.

(4) Higher Efficiency
Cycle time is reduced by high-speed and concurrent operations, and by minimizing loss time (10–30% increase in efficiency).

(5) Quality Improvement
Improved quality, stability, and yield rate of produced molds.

2.2 Ball screws for electric injection molding machines

In an electric injection molding machine, ball screws are used in its principal units such as the injection unit and the clamping unit, as well as in the nozzle touch and ejector units (Fig. 1). Among these, the ball screws used in the injection and the clamping units are required to have a particularly high load-carrying capacity. The ball screw in the injection unit, in particular, repeats reciprocations under high load at a relatively slow speed of 100–300 mm/sec in a short stroke range of about 20–150 mm. In order to inject plastic material of high melt viscosity at a high pressure, and to maintain the pressure, this ball screw is especially required to have an ultra-high load-carrying capacity and endurance, featuring a short stroke range.

3. Development of HTF Series Ball Screws for High Load Drive Application

The development of ball screws capable of operating with small strokes under heavy loads was one of the important tasks for converting conventionally hydraulically operated machines to all-electric machines, as represented by "2.2 Ball screws for electric injection molding machines." Ball screws used in such all-electric injection molding machines must be able to maintain their functions over a long period under much higher load conditions than that of machine tools, and are required to have a load carrying capacity higher than that of conventional type ball screws. NSK has developed the HTF Series ball screws (Photo 1) specifically applicable to such high-load drives.

The primary feature of the HTF Series is their improved practical load carrying capacity, owing to new engineering that permits even distribution of load in their nut. The second feature is their internal design (ball groove and circulatory path design) specifically developed to achieve enhanced dynamic as well as static load ratings.

The following subsections describe technical factors in detail, and present endurance test results of the HTF Series as well as specifications for their resin retaining pieces.

3.1 Even distribution of load

3.1.1 Load distribution of the ball screw

When axial load is applied to a ball screw, load upon each ball is generally given as an average of the load upon all the balls. Actually, however, the amount of load applied to each ball is not the same. The uneven distribution of load can be particularly significant when a ball screw has been mounted incorrectly, or when radial load or moment is too high, which all have an adverse effect on ball screw life[2].

Even the mounting error or offset load on the ball screw is small, if the actually applied load gets higher, thus adapting a long ball nut to increase load carrying capacity, and then the deviation of load distribution in such a long nut will be critically wider, which could result in a serious effect on practical use.

3.1.2 An example of load distribution analysis

Since uneven loading in a ball screw nut while under a high load can be significant, we developed a program that makes a 3D analysis of load distribution. With this program, we were able to develop the HTF Series[3], which distributes the load more evenly.

Fig. 3 shows the results of a case study in which load distribution of ball screws with conventional specifications and HTF Series specifications were analyzed and compared under the conditions shown in Table 1 and Fig. 2. We focused on the following three points to clearly identify the evenness of load distribution in the HTF Series:

(1) Arrangement of ball return tubes
Conventional screws have four circuits on the same circumferential phase, whereas the HTF Series screws have two central circuits on a reversed phase.

Table 1 Ball screw specification and conditions for load distribution analysis

Shaft diameter	100 mm
Lead	20 mm
Ball diameter	15.875 mm
Effective turns and circuits	2.5 turns × 4 circuits
Shaft supporting conditions	Fixed - free
Axial load	294 kN

(2) Nut flange position
The nut flange of a conventional screw is located near the fixed end of the screw shaft. In the HTF Series, the nut flange is located closer to the free end.

(3) Outside diameter of the nut
The outside diameter of a conventional type nut is 197 mm, and that of the HTF Series is 145 mm.

The horizontal axis in Fig. 3 represents the axial positions from the nut center taken as the origin. The left vertical axis represents loads that work on the individual balls that are on the position represented with the coordinate of horizontal axis. The right vertical axis represents the maximum surface pressures in the contact ellipses. The average values of the ball loads (maximum surface pressures) are represented by the broken line.

This figure shows a varying component of the load with a narrow 20 mm (one lead) cyclic range (narrow-range fluctuation component), and another component with a wide range that show an overall ball load increase as the position gets closer to the right-hand end (wide-range fluctuation component). For the HTF Series, there is little variation in load against each of the components, which indicates that the load is evenly distributed.

The three comparisons mentioned earlier do not take into consideration internal design modifications (See subsection 3.2), and so the average ball load, or average maximum surface pressure, of the types of ball screws appears to be equal.

3.1.3 Cause of uneven load distribution and countermeasures

Load distribution in the nut has both narrow-range and wide-range fluctuation components as described above. Here we will discuss the two main causes of uneven load distribution as well as improvements made to equalize ball load distribution in the HTF Series.

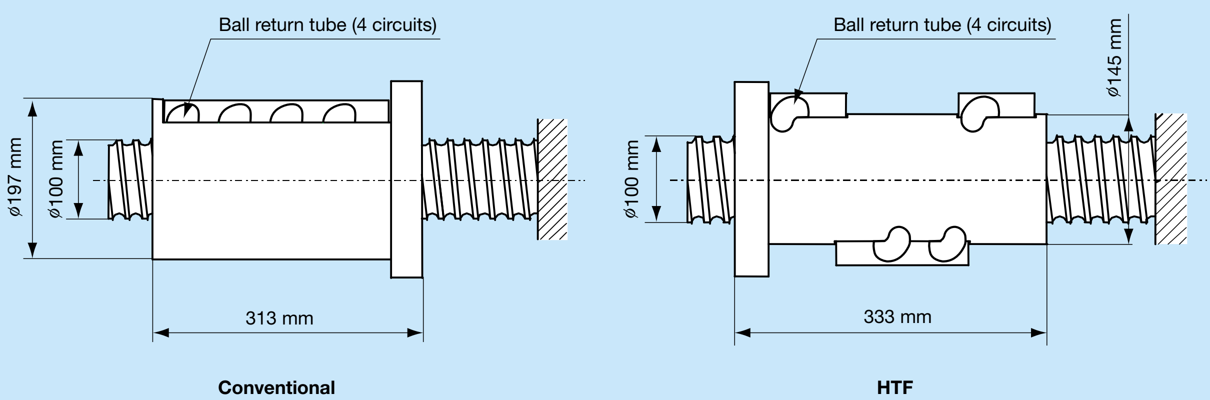

Fig. 2 Ball screw arrangement for load distribution analysis

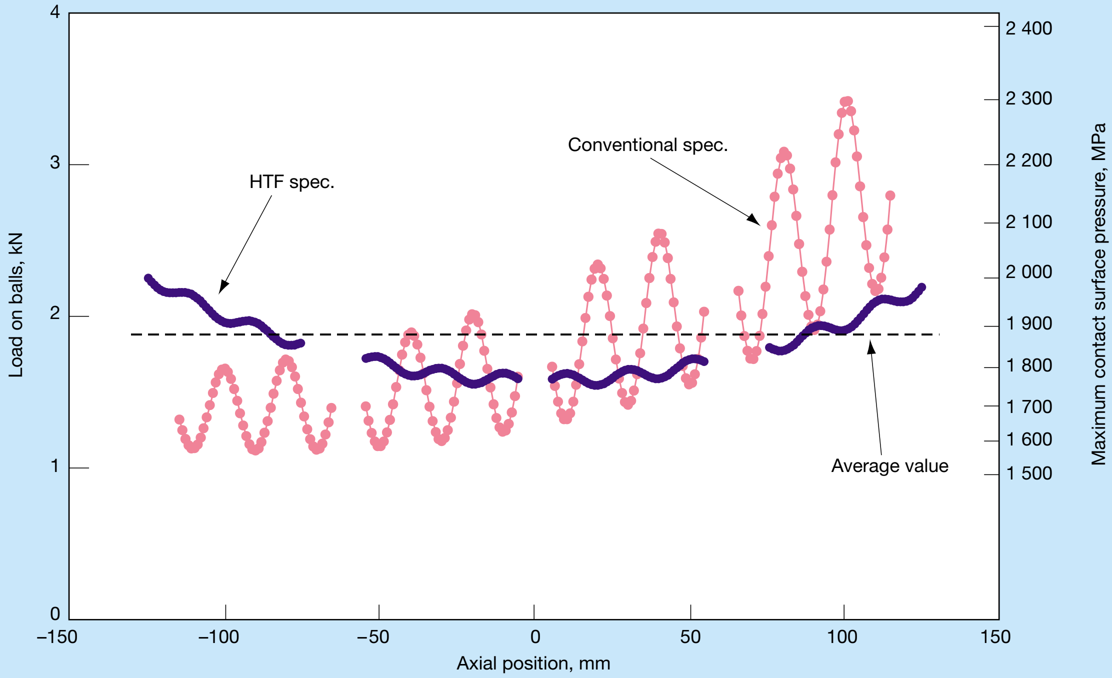

Fig. 3 Results of load distribution analysis

The narrow-range fluctuation component originates mainly in the asymmetry of the arrangement of balls that receive the load. The spiral of ball groove and the no-load zones will often create a three-dimensional asymmetric (axially and circumferentially around the nut center) arrangement of balls, thus resulting in uneven load distribution.

In the case of Fig. 2, for example, all four of the recirculation circuits under conventional specifications are arranged in the same phase. This layout results in having fewer balls under load in the ball return tube side than those of the other side, when we look it circumferentially. Therefore, moment load is balanced longitudinally but radial load is not balanced. Load on the return tube side is increased, resulting in the generation of narrow-range fluctuation component (single rotation cycles).

As a countermeasure, the HTF Series has the central two circuits reversed by 180°. With this arrangement, radial imbalance is improved while moment load balance is maintained and fluctuation component is minimized almost to zero. This arrangement, however, results in a nut that is longer by one lead.

Wide-range fluctuation component originates chiefly from the deformation of the screw shaft and the ball nut as the component parts. The deformation of the ball screws usually often approximates only to the proximities of the contact areas between the balls and the grooves which are taken as elastic, and the other areas such as screw shaft and ball nut bodies as rigid, based on the Hertzian theory. However, elastic deformation is also actually caused by load in other than the proximities of the contact areas of the balls and ball grooves of screw shaft and the ball nut. Additionally, the deformation of the component parts is proportionate to the first power of applied load on the ball screw while the elastic deformation of proximities of the contact areas is proportionate to the two-third power of load, so that the higher the load, the effect of the elastic bodies of screw shaft and ball nut is relatively greater, resulting in greater unevenness in the longitudinal distribution of load.

Fig. 4 shows the typical relation between load points (i.e. points of the screw shaft and the ball nut of a ball screw upon which external load is applied) and load distribution. Since the force acting upon the screw shaft and the ball nut is greater the closer you get to the load points, deformation of the component parts is greater at the flange of the ball nut and at the fixed end of the screw shaft. Hence, the combined deformation of a screw shaft and a ball nut decides the effect on load distribution.

When the load point of the nut is set nearer to the fixed end of the shaft, as shown in Fig. 4 (B), the effects of the deformation of the screw shaft and the ball nut will be interactively multiplied resulting in greater wide-range load distribution fluctuations.

When the load point of the ball nut is set nearer to the free end of the shaft, as shown in Fig. 4 (A), the effect of deformation of the screw shaft and that of the ball nut will offset each other. In addition, if the sectional area of the nut is arranged so that it is closer to that of the shaft to obtain better balance between the two, wide-range load fluctuations will be further reduced.

The HTF Series embody a screw shaft and ball nut combination, as shown in Fig. 4 (A), along with the use of an optimum ball nut outside diameter, and thus minimize wide-range load fluctuations, featuring a right-left symmetric load distribution curve.

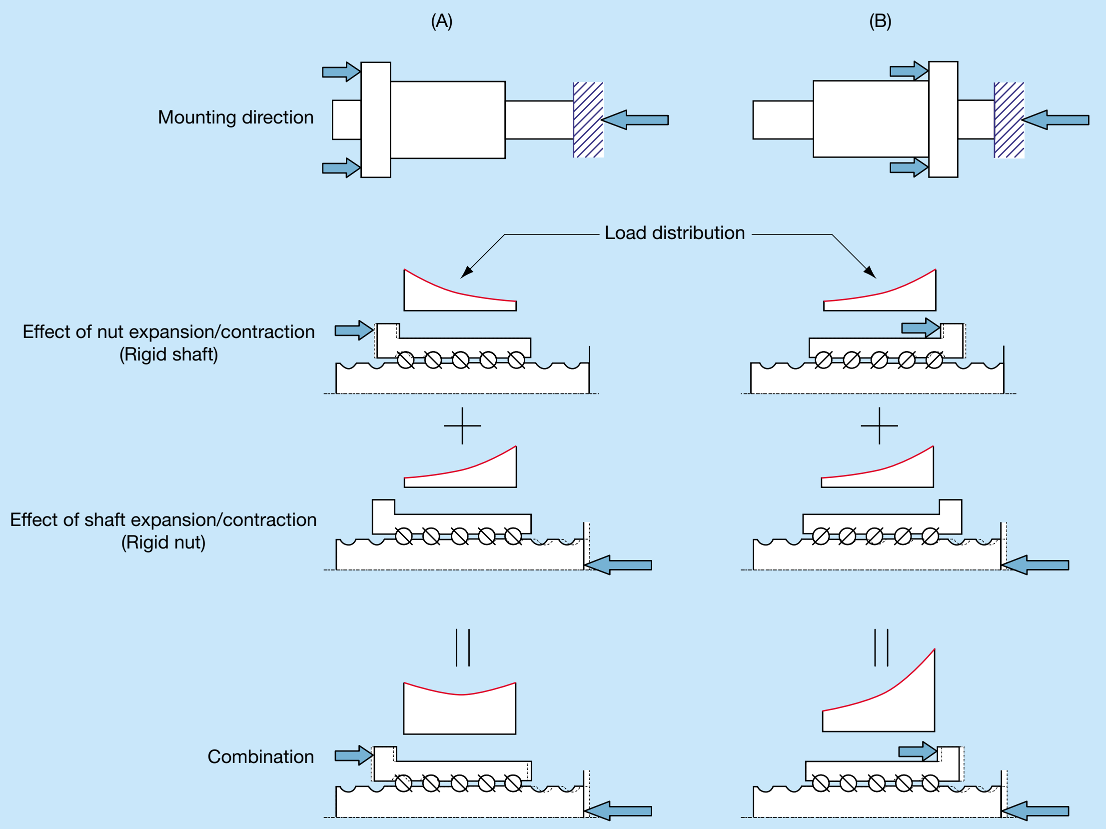

Fig. 4 Load points vs. load distribution

3.2 Internal design modifications

Apart from the equal distribution of load design stated above, the HTF Series has a modified ball groove and ball re-circulation circuit design suited specifically for high loads. The modifications include an increase in the ball and groove contact angle, an increase in the number of effective balls for receiving load, and an approximation of the curvature of grooves to that of the balls. Because of these modifications, HTF Series ball screws have a predictable life that is approximately 1.5 times longer than that of conventional ball screws for high-load applications.

3.3 Endurance testing under high-load conditions

High-load endurance tests under harsh simulated conditions of an injection axis for an injection molding machine were conducted to verify the improvements we made (See Fig. 5). Fig. 6 illustrates the loading profile. The highest axial load of 283 kN is extreme; much higher than the maximum contact surface pressure of 2 000 MPa, which has been the standard maximum reference load at NSK.

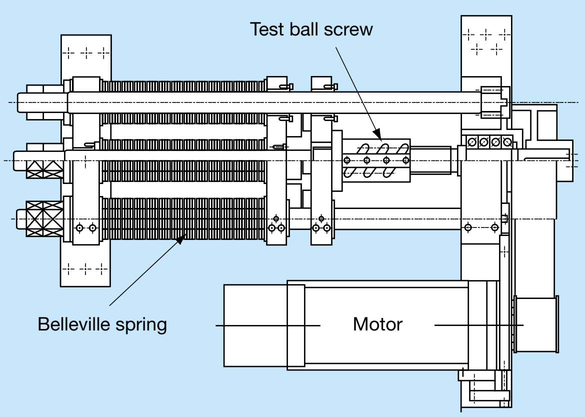

Fig. 5 Construction of high-load endurance test equipment

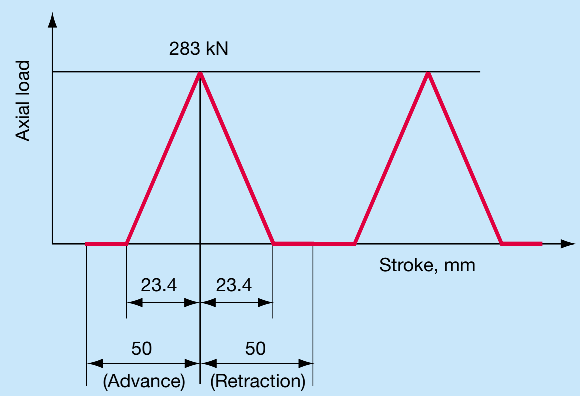

Fig. 6 Loading profile

Test results are shown in Table 2 and Fig. 7. The only differences in ball screw specifications were return tube arrangement and internal design. The outside diameter and mounting direction of the ball nut were kept the same for both the conventional ball screws and HTF Series ball screws.

The ball screws for the injection molding machine may continue to operate as long as it can transfer the load even if initial flaking has occurred. Its life may be defined as the total failure when excessive heat-up, excessive emission of noise, or lock of motion occurred. In this respect, the ball screws were tested to determine the number of cycles that occurred until initial flaking and then, without taking any corrective action regarding operating conditions, testing was continued until its failure.

TP1 of the HTF Series lasted 2.4 times longer before initial flaking, and 3.5 times longer until failure, when compared to conventional ball screw TP0. These improvements reflect advancements in load distribution with our reversed return tube arrangement and increased load carrying capacity thanks to internal design modifications.

Lubrication is also very important under such high-load operating conditions. Our test results show that TP2, which was lubricated with high performance grease with extreme pressure additives, had greater endurance than TP1, which was lubricated with conventional grease. In addition, TP3, which was lubricated with our newly developed grease for both high pressure and heat resistance, performed well, even after the ball nut was forcibly heated to 80°C.

3.4 Resin retaining piece for HTF Series

Machines operating under high loads will deform by heavy loads and, in some cases, it may be difficult to control installing accuracy of ball screws at assembly process. Consequently, offset loading and alignment errors

Table 2 Results of high-load endurance test

Shared specifications	Shaft diameter × lead	ø80 mm × 20 mm				
	Ball diameter	15.875 mm				
	Effective turns and circuits	2.5 turns × 3 circuits				
Test piece number		TP0	TP1	TP2	TP3	TP4
Tube arrangement and internal specifications		Conventional specifications	HTF specifications			
Resin retaining piece		None (Balls only)				Incorporated
Lubricant		Conventional standard grease		Commercially available grease for high loads	Newly developed grease	
Temperatures		Ordinary			High (80°C)	
Result	Cycles at initial flaking	1 050 000	2 500 000	No flaking (11 000 000)	No flaking (7 000 000)	No flaking (11 000 000)
	Cycles at time of failure	1 200 000	4 200 000	—	—	—

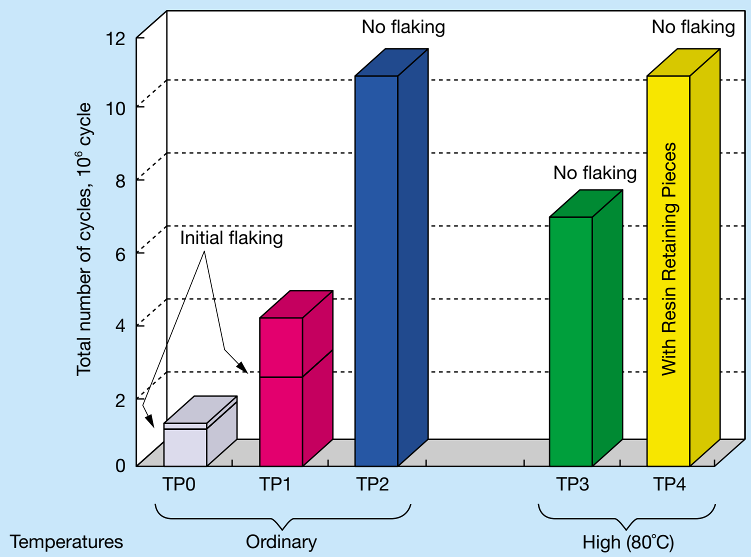

Fig. 7 High-load endurance test results

Table 3 Effect of resin retaining piece

Test piece number	TP A	TP B	TP C
Shaft diameter × lead	ø 100 mm × 25 mm		
Ball diameter	19.050 mm		
Effective turns and circuits	2.5 turns × 3 circuits		
Axial load	200 kN during advance, and 20 kN during retraction		
Stroke	70 mm		
Lubricant	Commercially available grease for high loads		
Resin retaining piece	None (Balls only)		Incorporated
Eccentric error (per 300 mm)	0.03 mm	0.3 mm	0.3 mm
Ball surface condition	Very good	Damaged	Very good

TP A
Balls only, small eccentric error

TP B
Balls only, large eccentric error

TP C
With resin retaining pieces,
large eccentric error

Photo 2 Ball Surface Appearance after Test

of the ball screws, in addition to heavy loads, can hinder smooth circulation of the balls, thus causing jamming of balls, and then adversely affect endurance of the ball screws.

To eliminate jamming of balls, NSK developed resin retaining pieces and incorporated them into the HTF Series. The recently developed NSK S1 Series™[4] also incorporate resin retaining pieces, which are functioning as the ball retainer whose practical application to ball screws had been considered difficult.

HTF Series ball screws with and without resin retaining pieces were tested for evaluation of their performance under various conditions including offset load. Test results are given in Table 3, and the surfaces of the tested balls are shown in Photo 2.

Test results indicate that the TP B, which had improper mounting and no resin retaining pieces, had significant troubles with the balls. Meanwhile, TP C, which incorporated resin retaining pieces and was improperly mounted, had positive results comparable to TP A that was properly mounted.

Table 2 and Fig. 7 summarize the results of a high-load endurance test for TP4, a grade of the HTF Series having resin retaining pieces. This test has thus far performed satisfactorily, scarcely showing any deterioration.

4. Conclusion

In the process of developing the HTF Series for high load all-electro servo linear motion drives that are more ecologically sound for injection molding machines, we discovered an effective means controlling load distribution as well as incorporating resin retaining pieces.

We believe that a combination of HTF Series ball screws with high performance grease and resin retaining pieces, provides a significant improvement in the endurance of ball screws for practical applications. We will continue efforts to further develop ball screws for high-load applications, including those beyond electric injection molding machines.

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4) H. Yamaguchi and T. Ohkubo, "Development of NSK S1 Series™ Ball Screws and Linear Guides," NSK Technical Journal Motion & Control, 11 (2001) 27-34.
*in Japanese

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Solid Lubricant SJ Bearings for High Temperatures

Bearings used in kiln cars are generally lubricated with a coating of conventional solid lubricant paste. Unfortunately, these bearings require additional lubrication after only a short interval. User demand has grown for a bearing that can be used continuously at high temperatures over a long period.

Conventional use of a soft metal or a solid lubricant paste lack the durability required for high-temperature and vacuum environments, such as with vacuum deposition equipment.

In response, NSK has developed the SPACEA™ series SJ solid lubricant bearings that achieves maintenance-free performance and durability in high-temperature atmospheric conditions and vacuum environments. Features, specifications, and the performance of our SJ bearings are described below.

1. Features

(1) Long life and maintenance free
Long life is achieved with a steady supply of lubricant to the rolling elements and raceway surface by the spacer joint. This ensures sufficient lubrication over a long period, and eliminates the need to constantly replenish lubricant.

(2) High-temperature compatibility
Sintered molybdenum disulfide-based material is used for the solid lubricant spacer joint, ensuring serviceability in temperatures up to 400°C in normal and vacuum environments.

(3) Torque stability
Other types of bearings have a strong tendency to suffer from torque fluctuation or bearing vibration due to insufficient lubricant film. NSK's SJ bearing achieves stable rotation because the lubricant film is maintained evenly on the rolling surface by the solid lubricant spacer joint during rotation.

2. Design and Specifications

Fig. 1 (a) shows a photo of a normal SJ bearing and a cutaway bearing and (b) features a cutaway drawing. Each cage pocket has two rolling elements, with a solid lubricant spacer joint positioned between specially treated balls. The spacer contacts the rolling element, which forms the minimum required solid lubricant film over the surface of rolling element and raceway surface. Long life is achieved with a steady supply of lubricant from the spacer joint. The cage design helps ensure running stability; minimizing any vibration, even when the spacer joint has become worn out.

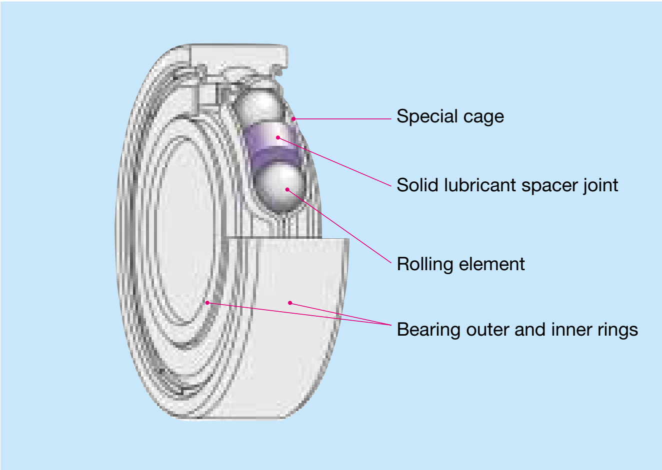
The solid lubricant spacer joint is made from sintered molybdenum disulfide-based material, which ensures effective lubrication in high-temperature atmospheric conditions. The durability of this bearing overcomes the problems of strength and wear, and achieves extended maintenance-free performance.

3. Performance

Results from an evaluation of running performance under normal atmospheric conditions (Fig. 2) show that bearings using conventional solid lubricant paste fail (seizure) after 30 hours. Our SJ bearing outperformed the conventional-type bearings with amazing results: durability was six times that of conventional bearings with solid lubricant paste and twice that of SJ bearings without cages.

Under vacuum conditions (Fig. 3), silver-coated bearings

(a) Cutaway photo



(b) Cutaway drawing

Fig. 1 SPACEA™ series solid lubricant SJ bearings suffered from excess torque, which then doubled after 650 hours. Even after 700 hours, running torque of the SJ bearings continued to drop, reflecting the superior transfer and adhesion qualities of SJ bearings.

Analysis results of SJ bearings under high-temperature conditions in a vacuum environment (Fig. 4) show minimal outgassing, even after heating to 300°C.

4. Application

Our SJ bearings provide outstanding performance in normal atmospheric and vacuum environments operating under high temperature conditions. Major applications include vacuum deposition equipment, kilns, kiln cars, iron works, and conveyors for high-temperature normal and vacuum environments.

5. Conclusions

In all high-temperature environments, high performance and maintenance-free operations are critical factors for enhancing productivity. NSK's SPACEA™ series SJ bearings meet the demands and requirements of customers in a wide range of fields.

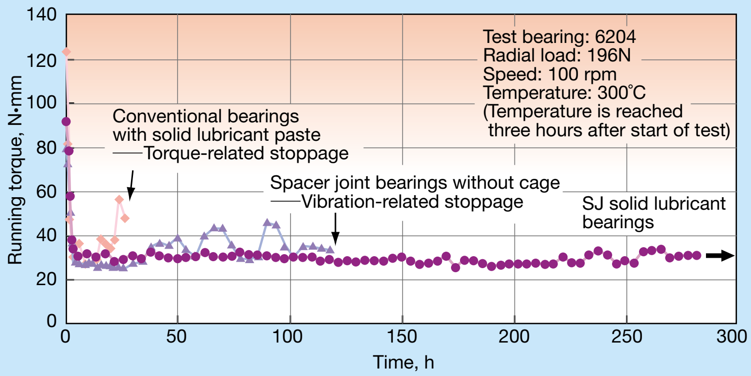


Fig. 2 Durability of bearings in high-temperature normal environments

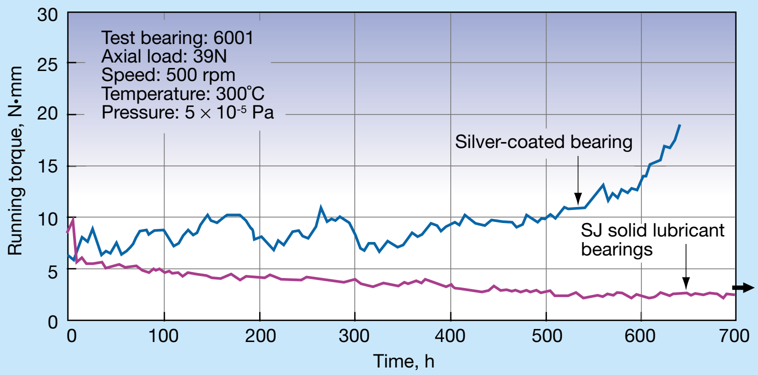


Fig. 3 Durability of bearings in high-temperature vacuum environments

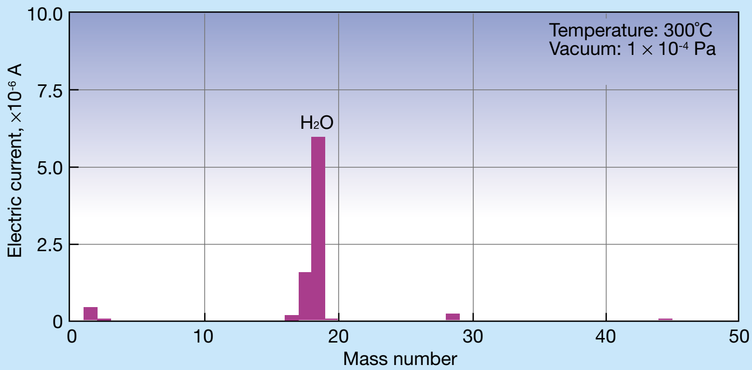


Fig. 4 Analysis results on outgassing of SJ solid lubricant bearings

Translide™—New Rolling Element Linear Motion Bearing

NSK linear guides are widely used for machine tools, various types of robots, transport mechanisms, and as guide elements for semiconductor production lines.

Conventionally, sliding guideways or cam followers are used for the transporting mechanisms. Recently, the use of linear rolling bearings has increased due to certain advantages, such as higher speeds, extended maintenance-free performance, less energy consumption, and the added benefit of improved durability for various machines and equipment. Above all, cost performance outweighs demand for accuracy and rigidity. This reflects the severe conditions where linear rolling bearings must operate including exposure to foreign matter.

NSK has responded to market demand by offering the Translide™, a new type of linear rolling bearing that supports specialized functions necessary for transport mechanisms. Details are provided in this article.

1. Features

Translide™ offers the same standards available with NSK linear guides in shape, dimension, and basic functions, with the following added features:

(1) Low price
A new rail machining method, a new ball slide design, and a newly designed external ball-recirculation circuit help bring about substantial cost reductions.

(2) Long life
An optimum ball diameter for a higher capacity design ensures long life.

(3) Superior dust resistance
High-performance end seals, bottom seals, and inner seals are standard equipment.
The dust-proof seals around the ball slide achieves

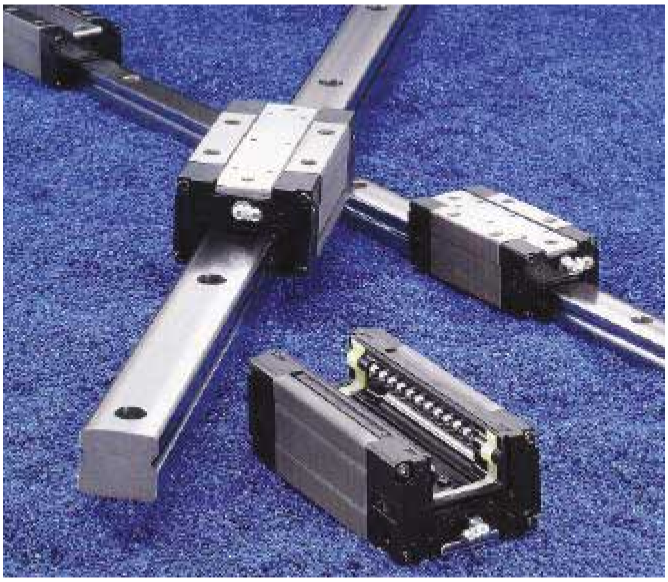


Photo 1 Translide™

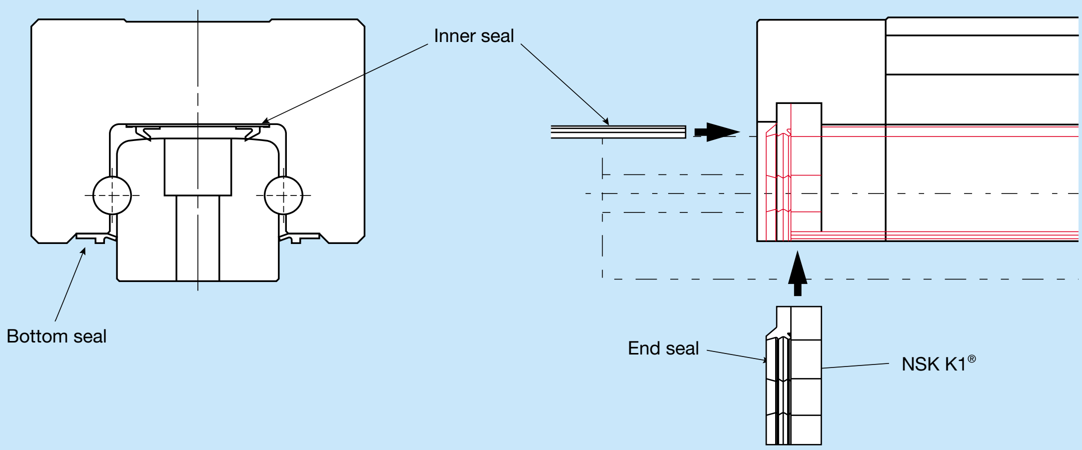


Fig. 1 Construction of the Translide™

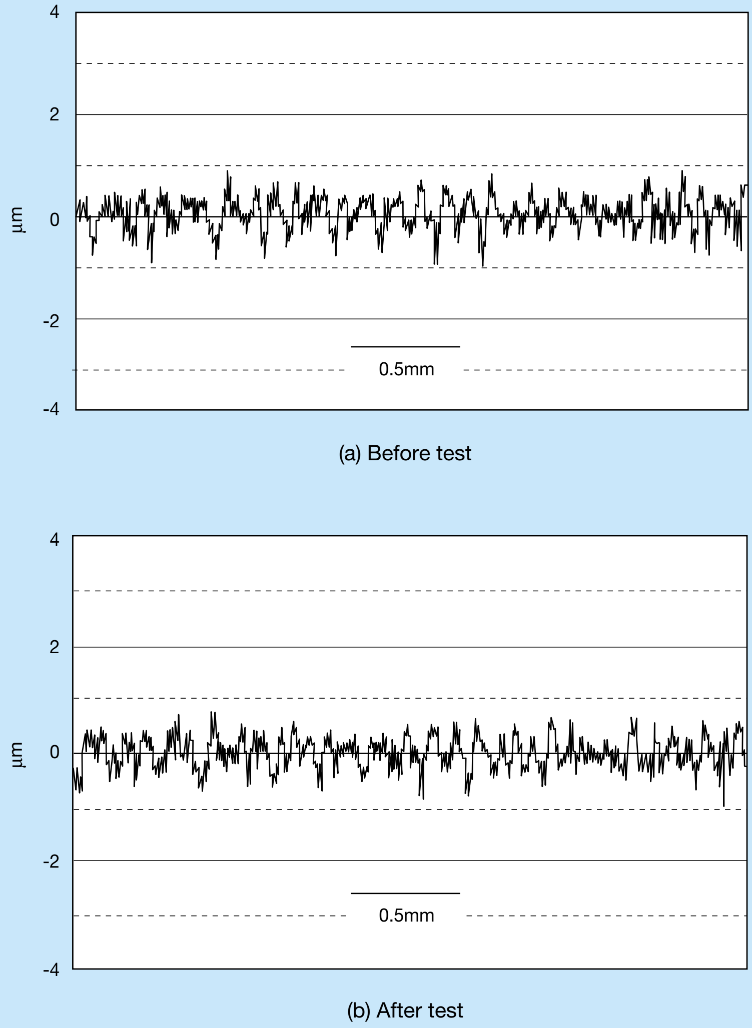


Fig. 2 Comparison of raceway surface roughness

extremely effective dust-proof performance in a transport environment exposed to foreign matter. In addition, mounting holes on the top surface of the rail have been replaced with mounting taps (Table 1, Type II) under the rail for greater harsh-environment performance.

(4) Maintenance free
Standard specifications include NSK K1® lubrication units achieving advanced durability for long-term maintenance-free service.

(5) Prompt delivery
The rails and ball slides of this series are produced and stored separately, and then matched at random as needed. Maintaining a standard stock of rails and ball slides reduces delivery times.

2. Structure

An image of the Translide™ is available in Photo 1 and the NSK K1® lubrication unit can be seen in Fig. 1. The seal configuration substantially improves dust-proofing and maintenance-free performance.

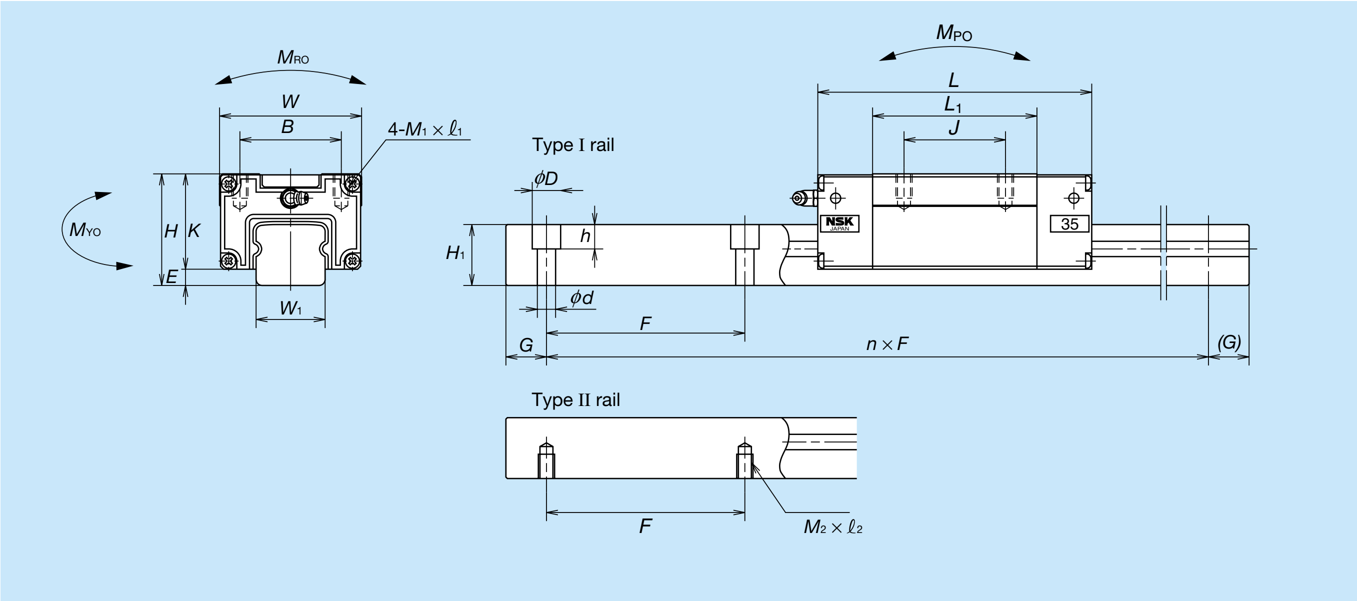
3. Accuracy, Clearance, and Durability

An exclusive accuracy class has been established for transport applications:

Running parallelism: 100 µm or less
Radial clearance: 60 µm or less

Fig. 2 compares the raceway surface roughness of a rail before and after durability testing using a Translide™ TS35 for the test piece. A heavy load was added externally to the ball slide while the Translide™ was operated continuously for the calculated life period. Testing was conducted with only the initial amount of packed grease that comes standard with this product; no additional greasing or lubrication was applied. The raceway groove of the rail had sufficient durability. Raceway surface roughness remained stable with no excessive wear, even after exceeding the calculated life.

Table 1 Dimensions



Unit: mm

Model number	Assembly		Ball slide							Basic load rating				
	Height		Width	Length	Mounting tapped hole					Dynamic	Static	Static moment (N·m)		
	H	E	W	L	B	J	M_1 × Pitch × ℓ_1	L_1	K	C (N)	C_0 (N)	M_{RO}	M_{PO}	M_{YO}
TS15AN	28	3	34	72.2	26	26	M4 × 0.7 × 6	39	25	7 350	8 760	68	47	51
TS20AN	30	3	44	87	32	36	M5 × 0.8 × 8	50	27	11 700	14 200	146	102	109
TS25AN	40	4	48	100	35	35	M6 × 1 × 9	58	36	16 700	20 000	246	168	168
TS30AN	45	6.5	60	115	40	40	M8 × 1.25 × 10	70	38.5	23 900	29 000	435	304	304
TS35AN	55	8	70	135.8	50	50	M8 × 1.25 × 12	81.8	47	35 900	40 900	748	489	489

Model number	Rail						
	Width W_1	Height H_1	Pitch F	Type I d × D × h	Type II M_2 × Pitch × ℓ_2	G (Recommended)	Maximum length
TS15AN	15	14	120	4.5 × 7.5 × 5.3	M4 × 0.7 × 6	20	3 040
TS20AN	20	15	120	6 × 9.5 × 8.5	M5 × 0.8 × 8	20	4 000
TS25AN	23	20	120	7 × 11 × 9	M6 × 1 × 9	20	4 000
TS30AN	28	25	160	9 × 14 × 12	M8 × 1.25 × 12	20	4 040
TS35AN	34	30	160	9 × 14 × 12	M8 × 1.25 × 12	20	4 040

4. Types

Table 1 shows the type and principal dimensions of this series. This product shares the same mounting dimensions as the LH Series of the NSK Linear Guide®. This allows interchangeability with the LH Series for incorporation in machines.

5. Applications

This product provides the optimum linear rolling bearing for various transport mechanisms. Applications include automobile manufacturing equipment, loaders and unloaders (machine tools), tire forming machines, woodworking machines, and others.

6. Conclusions

NSK offers the Translide™ as a competitively priced linear rolling bearing that is completely needs-oriented to the transporting mechanism market.

We will further improve the product, and expand the series.

High Lead Precision Rolled Ball Screws

There is a growing need for precision transport ball screws in the woodworking machinery and transport system markets. These ball screws must be low-priced, preloaded, and meet the accuracy grade of JIS Ct5 and Ct7.

In response to market demand, NSK has developed the High Lead Precision Rolled Ball Screw (Photo 1) that incorporates the required functions. An outline of this product is described below.

1. Features

(1) Low price and high performance
In addition to standardization, advanced machining technology has been introduced and further promoted for both the ball screw shafts and the ball nuts. The result is a new type of ball screw that offers smoother operation and higher speed that are substantially improved over conventional ball screws, while at the same time achieving a lower price.

(2) High speed
A new way of ball re-circulation circuit, which achieves a maximum speed of 150 m/min, has been employed.

(3) Long stroke capability
NSK's advanced machining technology and tools helped achieve a maximum screw shaft length of 6 500 mm.

(4) Compact
The outside diameter of the ball nut has been reduced by approximately 25% in comparison to the standard return tube type ball nuts.

(5) Maintenance free
This product is equipped with NSK K1® lubrication units, which have had successful results since marketing began in 1996. Customers can enjoy maintenance free operations for up to 10 000 km or five years.

(6) Suitable for a contaminated environment
On the assumption that a woodworking machine or a transportation equipment, to which the ball screw is installed, will be used in environments with severe exposure to foreign debris such as sawdust, the High Lead Precision Rolled Ball Screw is equipped with a new contact seal (Photo 2) that features high dustproof capability, low friction and high anti-wear capability, thus reducing heat generation in high-speed operations.

2. Specifications

(1) Accuracy and axial play
- Meets JIS accuracy grade of Ct5 and Ct7
- Axial play of 0 (Preloaded)

(2) Screw shaft
- Maximum screw shaft length 6 500 mm
- Abundant line-up of standard shaft end configuration

(3) Ball nut
- Optimal for nut rotation because of low-inertia moment/balance design

Photo 1 High Lead Precision Rolled Ball Screws

Photo 2 Contact seal

(4) Seal
- Use of a newly developed contact seal

(5) Lubrication
- Two types of grease available
  Standard specification: NSK grease AV2
  Clean specification: NSK clean grease LG2
  (Outstanding low dust generation)

(6) Permissible speed
- Speed of 150 m/min or 5 000 rpm
- Refer to “Precision Machine Components” catalog (CAT. No. E3159) for information on critical speeds and natural frequency of the screw shaft

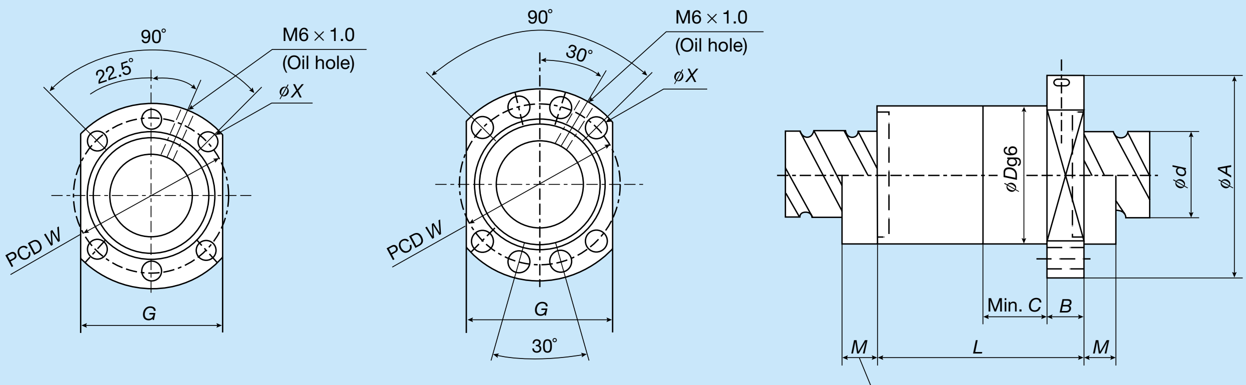
3. Content of series

Table 1 provides figures of the ball nut, type, and dimensions of this series.

4. Application

Woodworking machines, transport systems, feeders, and robots

Table 1 Principal dimensions



Shaft diameter 25, 32 | Shaft diameter 40, 50 | NSK K1® lubrication unit

Unit: mm

Model No.	Shaft diameter	Lead	Effective turns of balls	Basic load rating (N)		Ball nut dimensions									Maximum shaft length
	d	*ℓ*		Dynamic C_a	Static C_{oa}	*D*	*A*	*G*	*B*	*L*	*C*	*W*	*X*	*M*	
LPR2525	25	25	1.7 × 2	11 000	27 500	40	62	48	14	63	30	51	6.5	21	3 200
LPR3232	32	32	1.7 × 2	16 300	43 900	50	80	62	14	79	40	65	9	21	4 000
LPR4040	40	40	1.7 × 2	29 000	76 200	63	93	70	16	94	45	78	9	21	6 500
LPR5050	50	50	1.7 × 2	32 200	96 200	75	110	85	18	115	45	93	11	21	6 500

New Products

Megathrust Motor PM Series

Since 1994, NSK has been marketing the Megathrust Motor Y series not as a separate linear motor, but as a driver unit incorporating a linear guide and sensor. This product has been widely used for positioning and high-speed transfer systems in the semiconductor field.

Recently, requirements for increased speed and thrust have grown along with the expansion of applications for linear motors. To meet growing demand, NSK has developed a new permanent magnet (PM) linear motor as Megathrust Motor PM series.

1. Design and Specifications

The motor is shown in Photo 1, and its specifications are listed in Table 1.

(1) Motor main body

The slider, which incorporates a movable coil, is supported by linear guides that travel on a rack base to which magnets are mounted.

(2) Driver unit

The dedicated driver unit, which is a common feature of the Megathrust Motor Y series, can be linked to a computer or sequencer via an RS-232C serial communication interface. This allows input control for servo-on, internal program selection, and various position settings.

Additional features include pulse-train input, internal program selection, command/execution function, return to origin, and stroke end L_s input functions.

2. Features

(1) High-speed, high-accuracy positioning

The linear scale and UVW sensor provide drive control

Table 1 Specifications of the Megathrust Motor PM series

Item		Specifications
Motor type		Permanent magnet assembly, moving coil assembly
Maximum thrust	(N)	400/800/1200
Motor dimension	(mm)	200 (W) × 180 (L) × 73 (H): 400N product
		200 (W) × 300 (L) × 73 (H): 800N product
		200 (W) × 420 (L) × 73 (H): 1200N product
Slider mass	(kg)	7/14/21
Allowable mass	(kg)	40/80/120
Maximum rail length	(m)	30
Maximum speed	(m/s)*	2/1.5
Resolution	(μm)	1/0.5
Repeatability	(μm)	±1
Position detector		Linear scale
Drive unit		Drive unit dedicated for pulse train input / analog input / internal program

*Maximum speed varies according to linear scale resolution.

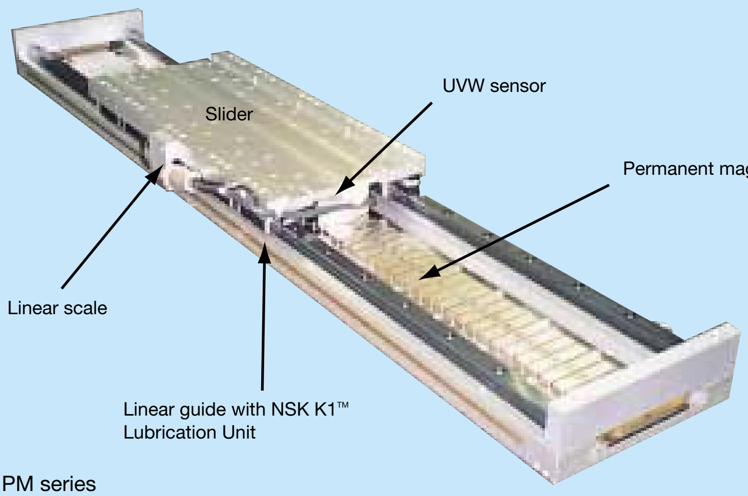


Photo 1 Megathrust Motor PM series

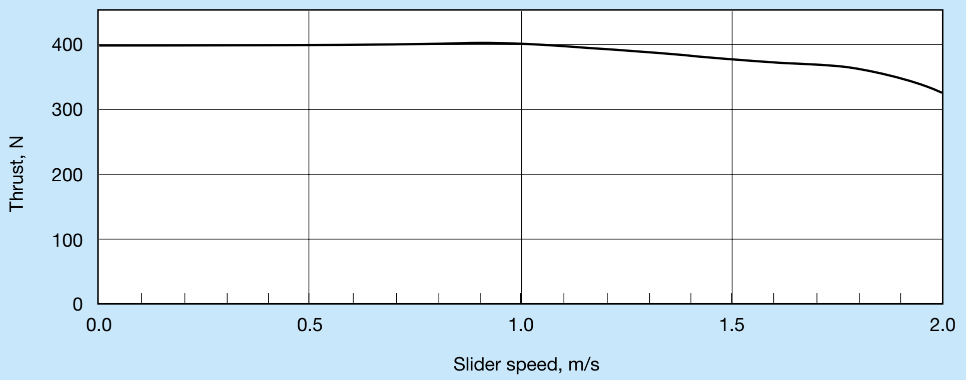


Fig. 1 Speed-Thrust performance of 400N motor (at AC 200V)

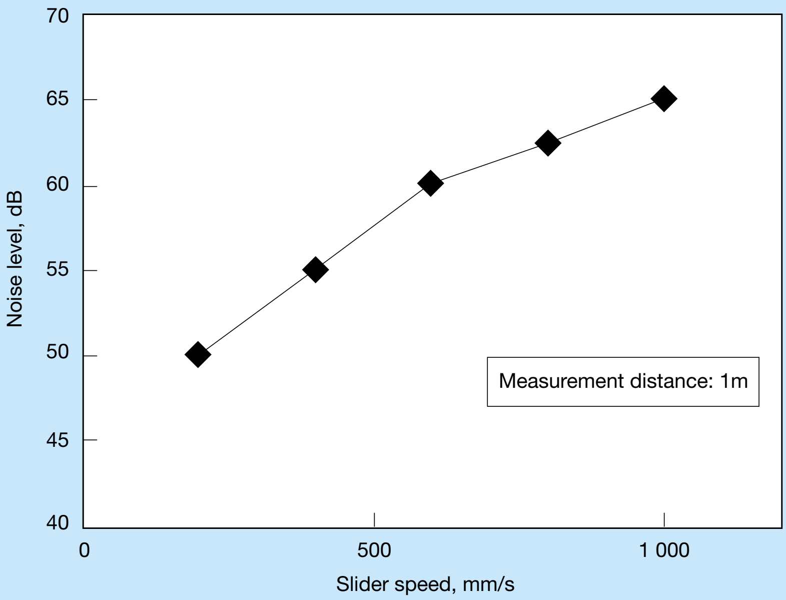


Fig. 2 Acoustic noise

necessary for full-closed control. This control ensures positioning performance at high speeds (2 m/s) and high accuracy (repeatability within ±1 μm).

(2) Improved thrust characteristics at high speed
enables high thrust output at high speeds (Fig. 1)

(3) Low noise
When electrical energy is applied, thrust occurs due to the action of magnetic induction. This thrust is used as an actuator. As a result, there is minimal fluctuation in absorption sound, thus assuring quiet operation (Fig. 2).

(4) Long life
The linear guide incorporates an NSK K1™ Lubrication Unit that regularly feeds extremely small amounts of lubricating oil. The guide can therefore operate for 10 000 km or for five years without replenishment of lubricating oil in a clean environment.

(5) Long stroke
This product can meet long stroke requirements by connecting rack bases (rails). A maximum rail length of 30m is available for accommodating various user needs. Unlike ball screw drive mechanisms, this linear guide product safely allows high-speed transfers.

(6) Multi-slider
The rack base can be readily configured to accommodate multiple sliders for greater independent control.

(7) Clean room applications
Since the coil assembly and the magnet assembly of linear servomotors have a non-contact design, they are ideally suited for clean room applications. Molded-Oil™ in combination with the linear guides also ensure high cleanliness.

3. Applications and Fields

NSK's Megathrust Motor PM series is combined with a linear guide to ensure easy operation. Additional services and technical support are available to according to customer's needs and requirements.

Table 2 Typical applications of Megathrust Motor

Applications	Requirements
Internal wafer transfer	Repeatability: 0.1 mm; low dust generation
Clean robot-system transfer	Repeatability: 0.1 mm; low dust generation
	High-speed positioning: 2 m/s; multi-slider
Surface mount equipment	Short-term positioning, high acceleration/deceleration
Wire bonder	Short-term positioning, high acceleration/deceleration,
	maintenance free, long life
Scanner	Speed stability
Inspection	Short-term positioning, multi slider
Inspection	High accuracy: nano micron; scanning constant velocity
PCB machine	High speed, controllability
LC transfer	High speed, high thrust

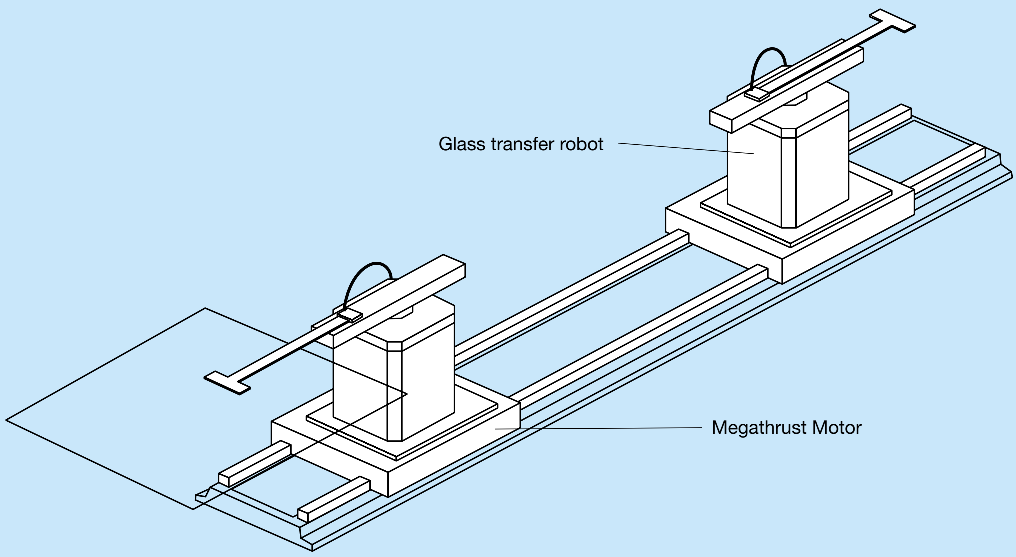


Fig. 3 Application in glass transfer machine

Megathrust Motors PM series and Y series are product lines that can be configured to meet a wide-range of needs.

Typical applications are shown in Table 2.

This product is often used in LCD and semiconductor manufacturing systems, proving applicability in high-speed surface-mount pick-and-place equipment applications where accuracy and repeatability (velocity, smoothness, acceleration, etc.), are emphasized.

An example of glass transfer is shown in Fig. 3.

4. Maintenance Free Motor

Although NSK Megathrust Motors do not require any scheduled maintenance, you should occasionally check the magnets for dust build-up or other contamination.

At NSK, we will continue to work hard to develop new technologies and improve upon current products that meet the needs of our customers.

New Products

R Series Robot Module™

NSK has developed the R series of its Robot Module™ lineup (Photo 1).

The focus of this series was to develop a high-performance orthogonal robot for applications where an articulated robot has been used due to limited weight capacity, rigidity, movement cycle time, and cleanliness of orthogonal robots.

Outstanding features of the R Series Robot Module™ include a low cost solution and a compact footprint, which is further enhanced by fine adjustment of its operating stroke range. These points, in particular, rank high as major issues involving end users of robotic systems. We are confident that the R Series Robot Module™ will satisfy these issues and meet market needs.

In addition, NSK also offers the P Series Robot Module™, which was designed with excellent cost performance for light to medium loads. These two series, which include the EXEA controller (Photo 2), fulfill a wide range of needs for robotic systems users.

1. Features

(1) Both P and R series are incorporated with MF Series NSK linear guides and ball screws that are equipped with NSK K1® lubrication units. These innovative units offer maintenance-free lubrication for use in clean environments.

(2) The absolute value encoder provides the absolute position upon power-up without requiring a home cycle.

(3) Improved controller functions include multitask operation, continuous path, 3-dimensional arch motion, palletizing function, and more.

(4) High precision operations and movement cycle time are achieved with a highly rigid mechanism, a high-response digital servo, individual acceleration/deceleration settings, and a sinusoidal curve drive.

(5) Seal belt construction to ensure high resistance to dust.

(6) Dynamic brake is provided to ensure safety.

(7) CE mark approved

(8) Unique, airtight construction ensures a class 10 rating of the international cleanroom standards. Contamination risks are further reduced by the use of LGU grease, which contains no metals. This feature is only for the R series.

2. Specifications

There are three module units in the R series: RS, RM, and RH. The RS and RM modules offer higher performance with large motor output, making them perfect for Z-axis applications with high-load and high-movement cycle time requirements.

Each module is available in four types characterized by ball screw lead, motor mounting position, reduction ratio,

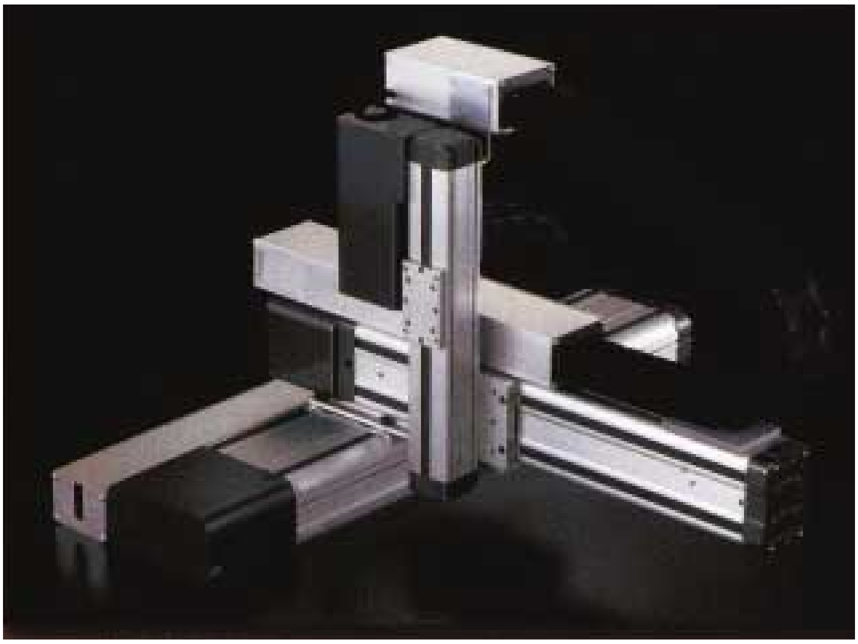


Photo 1 R Series Robot Module™

Photo 2 EXEA controller

and whether or not a brake is attached.

The R series uses the same EXEA controller that is used for the P series. Control of both a P series and an R series can be accomplished with just one EXEA controller.

Users run the controller in a Microsoft® Windows® environment where a graphical user interface provides easy setup and programming of the controller (Free download software is provided by NSK homepage.)

Please see Table 1 for the module main unit specifications and Table 2 for the controller specifications.

Table 1 Module main unit specifications

Module	Stroke (mm)	Repeatability (mm)	Maximum speed (mm/s)	Weight capacity (kg)		Transportable moment (Nm) * (Clean room specification)			Motor output
				Horizontal	Vertical	Roll	Pitch	Yaw	(W)
RS	130–630	±0.01	1 200	20	–	24	10	10	100
			600	20	8	(20)	(10)	(10)	
RS High-performance type	100–600		600	20	20	32	24	24	200
RM	250–1550	±0.01 (±0.02 for strokes exceeding 1000)	1 200	40	–	70	120	120	200
RM High-performance type			1 200	40	20	(60)	(120)	(120)	400
			600	40	40				
RH	300–2000		1 200	80	20	600	450	400	400
			600	200	40	(550)	(450)	(400)	

* The transportable moment represents the value at which the fatigue life becomes 10,000 km when moment in a single direction is continuously applied.

Table 2 Controller specifications

Item	Specifications
Power supply	AC 100V/200V/240V (CE mark approved)
Number of controlled axes	1 to 4 axes
Program capacity	Approximately 5 000 steps/128 programs
Maximum number of points	4 000 point
Data backup	Flash memory
Movement functions	Linear/circular interpolation up to 3 axes, continuous path, arch motion, palletizing
Acceleration pattern	Acceleration/deceleration along sinusoidal curve (Individual setting available)
General purpose I/O	16 points each. Extension available up to 64 points each (32 points for single axis controller)
PC interface software (Free ware)	Microsoft® Windows® 98/Windows NT®/ Windows® 2000 Professional compatible (CD-ROM)

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