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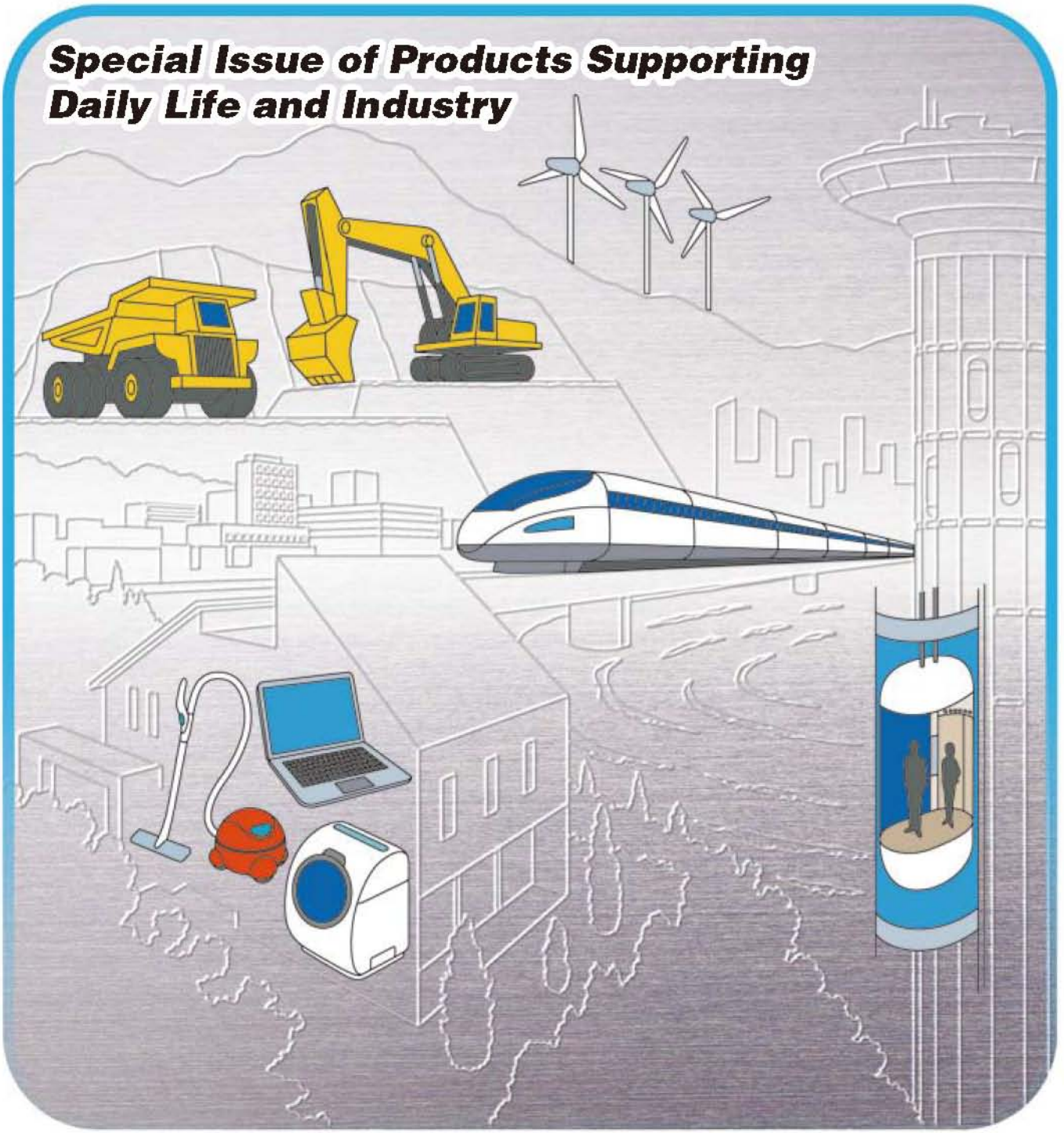

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Contents

Special Articles

New Products

For the Special Issue of Products Supporting Daily Life and Industry

Hisashi Machida
Special Adviser

Human beings have created civilizations and have developed technologies that have generated powerful forces, and have brought about great conveniences as well as inventing safe and indestructible machines. As a result, lifestyles have changed exponentially. We find ourselves using many products, which were not around as recently as 20 years ago; for example, electrical home appliances like flat panel TVs or DVD players, hybrid cars, and automotive fuel cell systems. Twenty years ago, who could have imagined our modern-day lives where we communicate via email or texting using handheld devices or personal computers? No longer are machines or devices able to simply "get by" with providing a convenience. We have entered an age where demand is growing on a global scale for products that lessen their impact on the natural environment and further reduce the consumption of global resources while lowering carbon dioxide emissions.

In Japan, bearings are referred as the "rice of industry," or rather a key or chief staple of industry. Various bearings with a bore diameter of 1.5 mm to an outside diameter of over 5 meters in size are mounted in machines. By enabling smooth shaft rotation, such bearings support our daily lives and various industries. About 150 bearings are incorporated into numerous electrical appliances intended for home use, and about as many bearings are used in vehicles. Therefore, by improving the basic performance of bearings, such as lowering torque, lowering noise, and extending service life, we can enjoy a more comfortable lifestyle, reduce our energy consumption, or we can build machines that are lightweight and operate with a higher degree of efficiency. I believe that the research and development of technologies and products by NSK can contribute to a greater compatibility between preserving the natural environment while living a comfortable lifestyle.

With this edition of Motion & Control, we have published our "Special Issue of Products Supporting Daily Life and Industry." We have introduced products from various industries such as railway rolling stock; construction machinery that support social infrastructures; industrial machinery such as pumps and compressors; the mother of all machines such as the lathe and injection molding machines; electrical home appliances such as vacuum cleaners; cooling fan motors used in information technology equipment; in addition to food-processing equipment and medical equipment. As the foundation of our four core technologies—material, tribology, analysis, and mechatronics—NSK will make efforts to solve global environmental problems and to address energy issues by achieving higher efficiency of products with the pursuit of greater convenience and a higher degree of comfort.

Hisashi Machida

Technological Trends of Railway Rolling Stock Bearings

Noriyuki Itoh
Industrial Machinery Bearing Technology Center

ABSTRACT

Trains are playing an ever-greater role in mass-transit systems as a means to deal with various environmental issues. Accordingly, as railway companies develop faster, more efficient, and safer trains for inter-city transportation, various rolling stock components must also be more highly reliable. This article describes rolling stock trends and specific technologies related to axle box bearings, gear unit bearings, and traction motor bearings. Such trends and technologies include the advancement of differing technologies around the world that are used in developing high-speed passenger trains that are capable of speeds exceeding 300 km/h, higher performance of speed sensor technologies, extended maintenance-free performance, lightweight designs, and global standardization.

1. Introduction

Railways dominate mass transit systems in many metropolitan areas and provide inter-city rail transport as a sort of linear transport network. The railway rolling stock used in such systems must not only ensure that safety requirements are met, which is of the utmost importance of any transit system, but must also ensure that facilities are highly durable so as to prevent failures that could obstruct the railway. In addition, the rail transport industry continues to pursue the development of technologies that can help lower maintenance costs, increase uptime, and extend maintenance-free performance without sacrificing safety. At the same time, inter-city railways promote high-speed, high-performance operations as they compete with air and highway transportation systems. Recently, rail transit systems have gained attention from the aspect of environmental issues. Recent technological trends and major technological challenges of railway rolling stock and their bearings under these circumstances are described below.

2. Technological trends

2.1 Railway rolling stock

In Japan and other countries around the world, demand is growing for higher railway speeds for passenger and freight trains. In particular, with commercial operation of France's TGV and Japan's Shinkansen bullet trains as prime examples (Photo 1), countries are pursuing the

Photo 1 N700 series Shinkansen bullet train Photo courtesy of Central Japan Railway Company

Table 1 Maintenance intervals extended for Shinkansen bullet trains

Type of train	Revised date of ministerial ordinance	Type of inspection		Former inspection interval	Extended inspection interval
Shinkansen bullet train	Announced in March 2002	Bogie inspection	Period	1 year	1.5 years (New train: 2 years)
			Running distance	450 000 km	600 000 km
		General inspection	Period	3 years	3 years (New train: 4 years)
			Running distance	900 000 km	1 200 000 km

practical application of high-speed rail transit capable of exceeding 300 km/h using proprietary technologies.

In Japan, practical operation of a train operating at 500 km/h in the future using linear motors will become more likely. At the same time, there have been moves to use direct drive motors (DDMs) on the axles for high-performance of rolling stock. Currently tests are being conducted for the practical use of DDMs in Japan. Tackling additional weight reductions in order to increase speeds, and dealing with environmental problems such as providing quiet-running performance and lower CO_2 emissions of rail transit systems, are some of the important issues that need to be addressed.

Also, railway operators can achieve significantly lower running costs by extending maintenance intervals, such as with the extended maintenance intervals achieved for the Shinkansen bullet trains as listed in Table 1 of this article[1]. In addition, the European Union continues to extend a seamless railway network throughout member countries by applying and advancing universal standards.

2.2 Railway rolling stock bearings

The bearings used in a railway axle box are shown in Fig. 1. These bearings are divided into three main applications: axle bearings, gear unit bearings, and traction motor bearings.

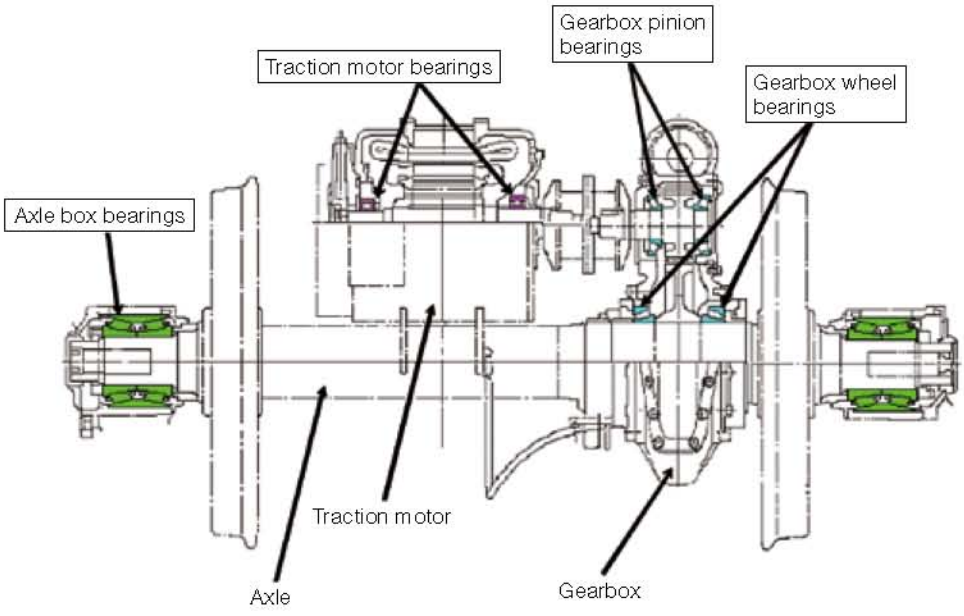

Fig. 1 Locations of railway axle box bearings

Photo 2 NSK rolling stock axle bearing with plastic cage

2.2.1 Axle bearings

Axle bearings support the axle directly and operate in harsh environments where vibrations between the rail and wheel are transmitted directly to the bearing. Under these circumstances, the life-enhancing requirements for long rolling fatigue life are increasingly severe. Accordingly, axle bearings are manufactured from highly purified steel, are subjected to non-destructive testing to detect material flaws, and in Europe, they undergo standardized ultrasonic inspections.

Furthermore, bearing conditions, which include temperature, vibration, and rotating speed, are monitored during operation and increasingly play an important role in ensuring reliability.

High-speed bearings that are packed with grease inherently require more sophisticated monitoring of bearing conditions to ensure reliability and smooth running performance. To this end, bearing makers continue to make advancements in systems that combine sensors with the bearing in order to diagnose any abnormal conditions. Unlike grease-packed bearings, oil-lubricated bearings can be more easily monitored with sensors that check oil levels, oil color, and check for worn particles with a magnetic plug. The relative stability of oil lubrication is another advantage.

As for bearings packed with grease, it is important to understand grease behavior within the bearing under high-speed rotation. More specifically, under high-speed rotation, grease distribution within the bearing needs to be meticulously controlled since centrifugal force easily flings the grease towards the seal. Thus, determining the best method for packing grease and the optimal amount that is packed are of a critical nature.

Furthermore, circumferential speed at the sliding surface of the seal increases under high-speed rotation, which needs to be restricted in order to prevent excess heat generation. Therefore, in order to reduce contact force where the seal pushes against the sliding surface, light-contact or labyrinth-type seals are used. In response to the high-temperature and high-speed operating conditions, heat-resistant rubber is used as the primary sealing material. However, seals for bearings that are operated under oil-bath lubricating conditions are configured for high-speed rotation as a measure against oil leakage with the seal having been developed by reviewing seal materials, material additives, and the seal configuration[2].

There is growing demand for bearings capable of operating with even further extended maintenance intervals. Such demand is especially strong for long-term non-overhaul inspections in excess of 1.2 million km for bearings used in high-speed railway rolling stock where improvements to grease will be imperative to prevent deterioration. There is also a trend towards switching from the use of conventionally pressed steel cages to plastic cages, which has become increasingly commonplace the world over with the same switch occurring more recently in Japan (see Photo 2). Through changes made to enhance grease performance, and by developing more highly reliable, high-performance sensor technology and component materials, there is a possibility that significantly longer maintenance intervals can be achieved.

Another trend is to further reduce the weight of bearing products. The Shinkansen bullet trains previously used a combination of triple-row bearings of a ball bearing and two cylindrical roller bearings—a combination that now consists of double-row combination cylindrical roller bearings or tapered roller bearings that can sustain axial loads. Axle boxes have also switched from using steel materials to aluminum alloy materials. The bearings used in metropolitan commuter trains and subways outside of Japan have trimmed weight by reducing and standardizing the dimensional difference between outside diameter of the bearing outer ring and bore diameter of the bearing inner ring.

In the meantime, differing standards have become more integrated among countries based on the Directive of Interoperability of the Trans-European High-Speed Rail

System by EC member countries. Standards for rolling stock axle bearings that have been established thus far include EN12080, EN12081, and EN12082. With these standards in place, bearing specifications, lubricating grease, and methods for evaluation performance and durability of bearings used for trains that operate across European country borders became widespread in Europe, thus clearing the way for securing a specified degree of high performance. A brief overview of EN standards related to bearings is listed in Table 2.

Furthermore, standards related to reliability, availability, maintainability, and safety (RAMS) have also been established in European Standards. Similar standardization is moving forward in Japan as well.

2.2.2 Gear unit bearings

Bearings for the gear unit, which transfers traction motor output to the axle, include support bearings for the pinion shaft and the gear wheel where tapered roller bearings have been used conventionally. The pinion shaft, which is an input shaft, rotates at high speed and is subject to vibrations from the coupling where it might cause the bearing cage to suffer from fatigue breakage or wear damage. Therefore, the cage used in a gear unit bearing is typically of a stronger type and has a soft-nitrided surface layer.

Meantime, in order to eliminate the need to make endplay adjustments in the axial direction for tapered roller bearings, cylindrical roller bearings are increasingly used in recent years[3]. With the use of a double-helical gear for the pinion, which cancels out axial loads, there is less load on the bearings. In addition, the tapered roller bearings that are used in this application have rollers with optimized end faces and ribs as a measure against the risk of seizure at the contact area between the roller ends and ribs.

As future operating conditions involve increasingly higher speeds and heavier loads, greater accuracy in estimating dynamic load acting on the bearing in the gear speed reduction transfer system must be improved in order to achieve bearing weight reductions. Fatigue analysis of the bearing raceway surface is one effective means for estimating this actual load[4].

2.2.3 Traction motor bearings

As a greater number of traction motors adopted brushless motors, bearing life began to exert an influence on the maintenance interval of the traction motors since bearings were the only sliding parts in such a motor. These bearings, which were initially packed with standard lithium-soap grease, were typically mounted in the traction motors used for the Shinkansen bullet trains. To further extend long-life performance, the base oil in the lithium-soap grease was changed to synthetic oil. Since ensuring long-term grease replenishment of bearings during operation plays an important role in ensuring enhanced service life, a bearing cover with grease pockets for retaining grease around the bearing has been proposed[5]. Life enhancement with grease lubrication has been implemented for ball bearings by replacing conventional pressed steel cages with machined brass cages in order to take advantage of the benefits of grease

Table 2 EN standards for rolling stock bearings

Standard	Details
EN12080 rolling bearings	Basic bearing specifications; established material cleanliness, marking, and sampling inspection; conduct defect inspections of bearing interior and surface areas; conduct ultrasonic inspections, eddy current testing, and strength testing of plastic cages.
EN12081 lubricating greases	Established to clarify minimum quality requirements of grease for rolling stock axle bearings. Grease is divided into two groups according to running speed of rolling stock: a) 200 km/h or less, b) higher than 200 km/h. Grease approval based on results of various grease performance evaluation tests, bench tests, and durability tests. Durability tests conducted with actual rolling stock using EN12082.
EN12082 performance testing	Performance and durability standards for journal boxes including rolling stock axle bearings and grease, including standards for bench tests and actual rolling stock tests are applied. Bench testing includes testing and evaluating two bearings simultaneously. Conduct testing with actual rolling stock. Inspect for abnormalities after testing and evaluate deteriorated grease.

lubrication.

Unlike the bearings in a traction motor of a locomotive, traction motor bearings of a railroad car are subjected to relatively light loads. Consequently, these traction motor bearings are more likely to become damaged or fail due to skidding of the rolling elements where oil film formation is hampered by slippage due to the lack of driving force from the inner ring acting on the rolling elements. In consideration of such risks, the importance of bearing internal specifications is on a par with that of the lubricant.

In addition, electrical insulation of bearings has become mainstream as a measure against electrical corrosion where direct current or alternate current flows through the traction motor bearings causing damage that consists of craters resulting from arcing and burning through the thin oil film at contact points between the bearing raceway and rolling element surfaces. Typically, electrically insulated bearings are sprayed with a ceramic material or have a resin material molded onto the outer ring (see Photo 3) where the higher the impedance of the coating film, the better the insulating performance. So-called hybrid bearings, which feature ceramic rolling elements, are also being used to counter electrical corrosion by taking advantage of their low capacitance, which further increases impedance.

Finally, prototypes of direct drive motors (DDMs) are currently being researched and developed with an aim towards reducing power consumption and eliminating gear noise associated with DDMs.

3. Major technological challenges for the future

In the past, efforts have been made in this field to gather field data on equipment under real-world everyday-use conditions and to develop simulation technologies involving software and hardware where data from simulation models can be analyzed. These efforts are based on an awareness of the importance of fully understanding actual operating conditions in which bearings are used, and based on the imperative to conduct evaluations in which actual operating conditions are reproduced. Such efforts are critical in successfully developing highly reliable railway rolling stock and are critical in improving performance. Examples of such efforts, as related to Shinkansen bullet trains, include the gathering of field data on roller motion in cylindrical roller bearings[6] and gather field data on load distribution of rolling elements under deformation in an axle box[7]. Technical requirements are continually changing while engineers attempt to gather precise field data, which is confirmed through a sequence of coordinated efforts that include reproducing the same field data using simulation models. Once the results are analyzed and verified, efforts are refocused on continually making further improvements to ensure even greater accuracy. These are just some of the basic technological challenges that are constantly addressed in any effort of research and development.

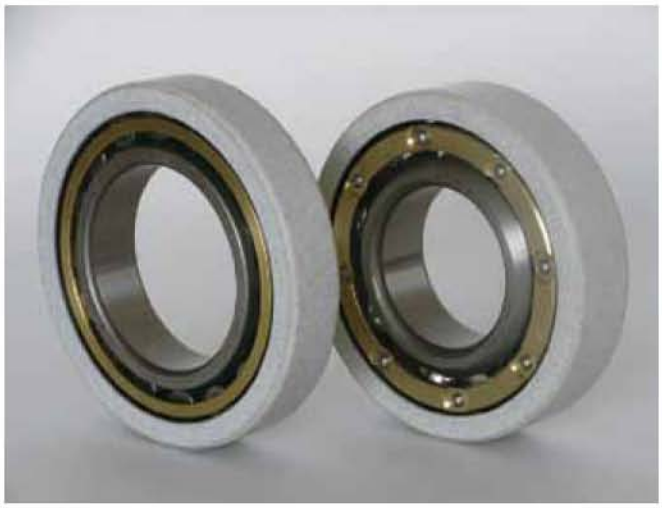

Photo 3 Cylindrical roller bearing and ball bearing with electrically insulated outer ring for use in traction motors

4. Postscript

Railway operators have typically placed significant importance on reliability over the long term in regards to railway rolling stock. In order to meet the needs of rolling stock of future railways, component makers need to design products that further enhance the capabilities of rolling stock for an ever-expanding range of operating conditions and environments. Such developments will require that designers take advantage of advancements in both software and hardware. Rolling stock bearings are in a prime situation to take advantage of not only advancements in materials, but also advancements in sensors and integrated intelligent systems. Such technological trends will likely play an ever-increasing role in ensuring long-term reliability for rolling stock.

Some information in this article has been previously published in the Monthly Tribology.

Noriyuki Itoh

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Technological Trends of Bearings for Construction Machinery

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ABSTRACT

Construction machinery are integral to building the infrastructure that help to make our daily lives more comfortable. Such construction machinery, which include crawler dozers, wheel loaders, hydraulic excavators, off-highway trucks, and many more, use all kinds of bearings. Bearings for construction machinery are subjected to a variety of severe operating conditions that include heavy and shock loads, light loads at high speed, or heavy loads at low speed. NSK has been developing specific bearings for various components of construction machinery that meet customer needs for long life and high reliability. The technological trends of bearings for a hydraulic excavator, which is a typical type of construction machinery, are presented in this paper.

1. Introduction

Construction machinery are used to safely and effectively build the infrastructure that helps to make our daily lives more comfortable. One forte of the construction machinery industry is its high degree of mobility, which can be readily applied towards the development of basic infrastructure such as roads, the development of community facilities such as waterworks and sewerage systems, making improvements to social-infrastructure such as urban development, and recent investments in socioeconomic infrastructure in developing countries such as BRICs.

Bearings of all types are used in a wide range of construction machinery, including crawler dozers, wheel loaders, hydraulic excavators, off-highway trucks, and more. In addition to bearings that are made to standardized ISO tolerances and dimensions, some bearings, which are specifically designed for use in construction machinery, are used extensively.

Construction machinery bearings are subjected to a variety of severe operating conditions that include heavy and shock loads, light loads at high speed, or heavy loads at low speed. NSK has been developing specific bearings for various components of construction machinery that meet customer needs for long service life and high reliability. In this article, we will introduce and discuss the bearings that are used for hydraulic excavators, which are representative of the construction machinery industry.

2. Bearings for hydraulic excavators

Crawler dozers enjoyed their heyday until the 1970s after which their production volume in Japan was surpassed by that of hydraulic excavators. Since then, the production volume of hydraulic excavators has grown to occupy half that of all construction machinery built in Japan (Fig. 1). Some of the primary bearing applications in a hydraulic excavator include bearings for the following: swing drive motors for rotating the upper structure; speed reducers for controlling travel motor speed; and hydraulic pumps that force oil flow through the system (Fig. 2).

2.1 Bearings for the swing drive reduction gear

The swing drive reduction gear, as its name suggests, is the reduction gear for the swing drive of the upper carriage. In recent years, the trend has been to make such reduction gears more compact while increasing torque output. Therefore, bearings for the swing drive reduction gear have had to meet requirements for higher reliability under heavy load conditions and limited space.

The bearings for the main shaft of this reduction gear are primarily spherical roller bearings (Photo 1). Spherical roller bearings consist of barrel-shaped rollers, an inner ring, and an outer ring that features a spherical raceway, which gives the bearing the ability to accommodate some misalignment. As a result, a spherical roller bearing rotates with sliding at the contact area between the inner and outer ring raceways and rolling surfaces of the rollers. NSK has clarified that the tangential force (friction force) generated on the raceway surface due to sliding influences fatigue life[2]. Accordingly, NSK commercialized a new series of High Performance Standard (HPS) spherical roller bearings that utilizes a special process on the outer ring raceway that reduces tangential forces and makes it possible to extend fatigue-life performance of the bearing. In comparison

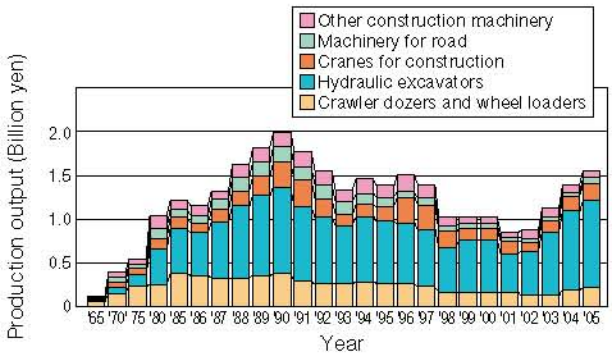

Fig. 1 Transition of construction machinery output in Japan[1]

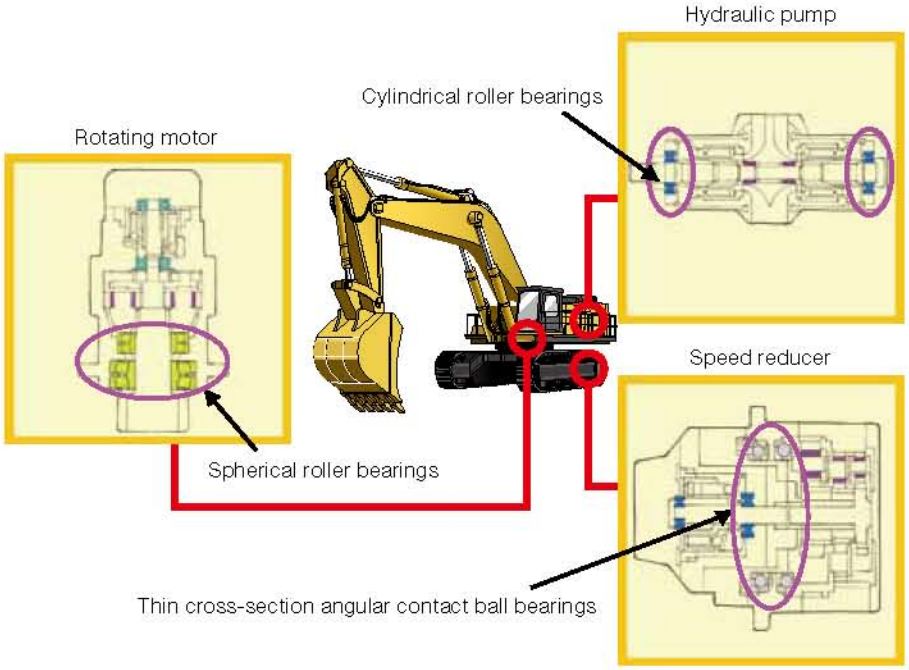

Fig. 2 Bearing applications in a hydraulic excavator

to conventional spherical roller bearings, the HPS series achieves a significant degree of extended life performance (Fig. 3). In addition, life has been further extended with a higher degree of reliability through the use of an improved cage made from nitrided pressed steel (Fig. 4).

2.2 Bearings for the travel motor reduction gear

The reduction gear in a travel motor is what drives the undercarriage track components of the excavator. Bearings used in the reduction gear are subjected to a harsh working environment, due to heavy loads, shock loads, and low operating speeds. The main shaft of the reduction gear uses matched angular contact ball bearings or tapered roller bearings that have non-ISO special dimensions. These bearings feature a thin cross section, which gives them a sufficiently low profile for use in tight spaces. Due to the harsh conditions of heavy loads and shock loads, these bearings are subjected to moment loads, which require bearings that are highly durable and offer a high degree of rigidity. NSK has thus optimized the internal specifications of these bearings using sophisticated analysis technology in order to fully meet customer needs. For example, NSK developed a new type of retainer that consists of resin separators for these angular contact ball bearings (Fig. 5). These separators allow the use of an increased number of balls in the bearing in comparison to a bearing using a conventional one-piece pressed steel cage. The result is a bearing that achieves higher degrees of capacity, durability, and rigidity. In addition, the use of resin separators in tapered roller bearings allowed for a 20 % size reduction, in comparison with angular contact ball bearings (Fig. 6). Furthermore, rigidity was increased by 30 % without effecting any change in static load rating.

Photo 1 NSKHPS spherical roller bearing[3)]

2.3 Bearings for the hydraulic pump

A hydraulic pump is the key component in the hydraulic system of a construction machine. It is the prime mover that forces fluid to flow under high pressure through the system, which is used to drive the hydraulic cylinders and the hydraulic motors of an excavator. Hydraulic pumps are exposed to hydraulic fluids that reach temperatures in excess of 100 °C. Consequently, bearings for these pumps must be highly resistant to high temperatures. The bearings used in hydraulic pumps are typically cylindrical roller bearings. In these bearings, NSK uses cages made of linear polyphenylene sulfide (L-PPS). These L-PPS cages have demonstrated excellent durability under conditions of exposure to high-temperature lubricating oil. In a conventional cylindrical roller bearing, polyamide resin is

typically used for the cage material. Unfortunately, this resin material tends to deteriorate and weaken under conditions of exposure to high-temperature lubricating oil. Conversely, L-PPS cages deliver high-strength performance even at high temperatures (Fig. 7), and offer sufficiently high reliability under conditions of exposure to high-temperature lubricating oil.

3. Other bearings for construction machinery

The recent development construction machinery using hybrid or electric motor drive systems has led to the replacement of hydraulic motors with electric motors. The bearings used in these electric motors frequently suffer electrical corrosion. As a measure to prevent electrical corrosion, NSK developed ceramic-insulated bearings. These are bearings that are insulated from electrical current by spraying a ceramic material on the outside surface of the outer ring, which forms an insulating barrier against electrical corrosion (Photo 2). NSK's ceramic-insulated bearing is dimensionally interchangeable with current standardized bearings since the bearing conforms to the ISO Dimension Plan. Furthermore, the insulation resistance of this bearing is 1000 MΩ or more (Table 1), which solves the problem of electrical corrosion.

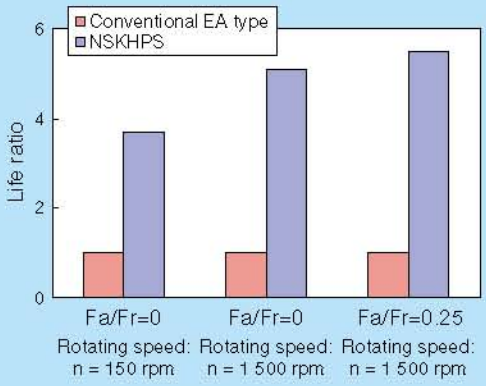

Fig. 3 Life test results[3]

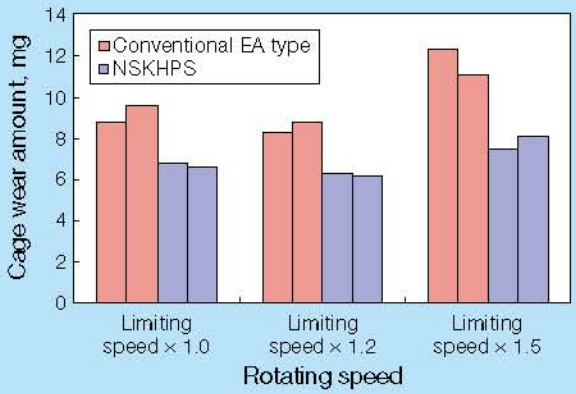

Fig. 4 Cage wear evaluation results[3]

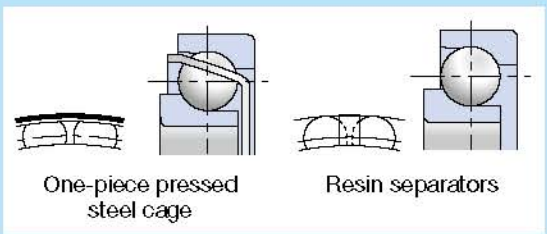

Fig. 5 Thin cross-section angular contact ball bearings

4. Postscript

Various applications of NSK bearings for a hydraulic excavator were described above as an example of their use in construction machinery.

At present, the construction machinery market is

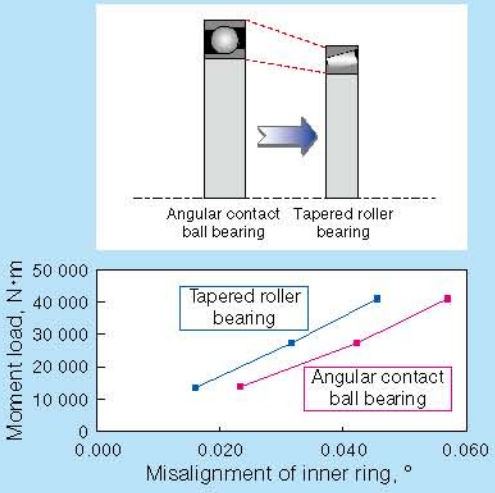

Fig. 6 Comparison of thin cross-section angular contact ball bearing and thin cross-section tapered roller bearing

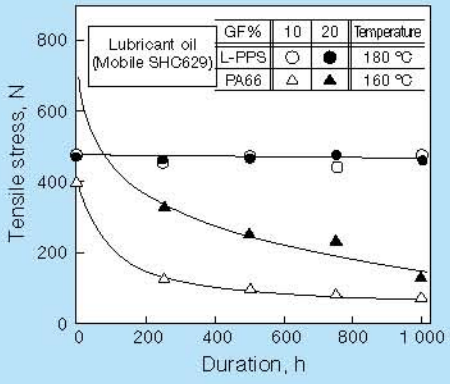

Fig. 7 Change in tensile strength of snap cages[4]

enjoying increased demand in the emerging economies of resource-rich countries, such as the so-called BRIC nations—Brazil, Russia, India, and China. In the meantime, the industry is confronted with important environmental concerns. Through continual advancements in proprietary technologies, NSK can develop environmentally friendly bearings through emphasis on low torque for less heat generation and improved fuel economy, quiet-running performance, and compact design in addition to the more traditional aspects of long life and high reliability. NSK will continue to contribute towards the progress of construction machinery for the future.

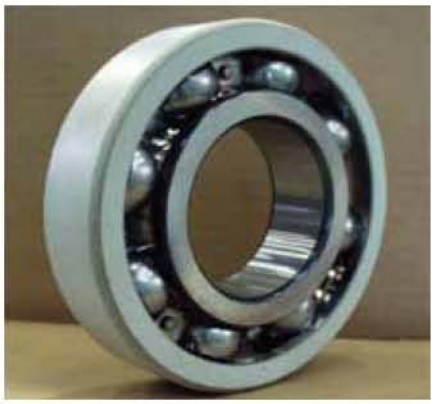

Photo 2 Ceramic-insulated bearing

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Haruo Kamijo

Table 1 Performance test results of ceramic-insulated bearings[5)]

No.	Test items	Details	Test results
			Ceramic-coated bearing
1	Rapid acceleration	Verify temperature rise under rapid acceleration immediately after packing grease.	No abnormal temperature rise
2	Initial insulation resistance	Insulation resistance value when DC 500 V is applied.	1 000 MΩ or more. No problems noted.
3	Initial capacitance	Capacitance via the housing fit.	2.10 nF (6311)
4	Mount/dismount	Measure strength of insulation coating and change in insulation resistance after mounting with and dismounting from the housing.	Insulation resistance: standard value or higher. Insulation coating: no abnormalities
5	Insulation resistance temperature dependency	Measure relationship between bearing temperature and insulation resistance.	100 MΩ or more No significant decline.
6	Capacitance temperature dependence	Measure relationship between bearing temperature and capacitance.	Negligible change.
7	Thermal degradation	Measure change in insulation resistance and capacitance after repeating 20 cycles of thermal testing. (1 cycle = 130 °C → ambient temperature → –10 °C)	Insulation resistance: standard value or higher. Capacitance: no significant changes.
8	Liquid immersion	Measure change in insulation resistance and capacitance when bearing is immersed in heated kerosene or bearing cleaning fluid, and grease	Insulation resistance: standard value or higher. Capacitance: no significant changes.
9	Drop impact	Observe insulation coating and measure any change in insulation resistance after drop impact testing onto a surface place from a height of 100 mm.	Insulation resistance: standard value or higher. Capacitance: no abnormalities.
10	Humidity cabinet	Measure change in insulation resistance and capacitance after repeating 20 cycles of humidity testing. (1 cycle = ambient temperature with humidity → 40 °C with 85 % humidity)	Insulation resistance: standard value or higher. Capacitance: no significant changes.
11	Rotation	Compare temperature rise from ambient temperature with that of a standard non-insulated bearing after temperature saturation.	Temperature rise is equivalent that of standard bearings.
12	Dielectric breakdown	Verify dielectric strength and determine if the bearing suffers from any breakage.	4 kV or more

Bearing Technology for Industrial Compressors

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ABSTRACT

Numerous types of compressors are used in almost every industry throughout the globe. In this paper, we present some basic concepts as they relate to a few types of compressors. We will then discuss the types of bearings that are most suitable to such applications, especially in regards to bearing performance requirements and related bearing technologies that can be applied to screw compressors used in industrial applications.

1. Introduction

A compressor, which is used in various applications, is a machine that compresses a gas by the application of pressure. For example, compressors are used extensively in plant equipment, air ventilation equipment at public works construction sites, domestic-use and commercial air-conditioning systems, refrigerators, and cold-storage facilities.

Compressors can be classified according to their method of compression: dynamic (turbo or kinetic) type or positive displacement type. The positive displacement classification can be further divided into subcategories: reciprocating or rotary (Fig. 1).

Compressors of the dynamic (turbo or kinetic) classification compress gas using the rotational motion of an impeller. Compressors of the positive displacement classification compress gas by confining volumes of gas within a closed space. Furthermore, compressed gases can be divided into three classifications: air, processed gas (for the chemical industry), and refrigerants (for refrigerators and air conditioners). Dynamic compressors typically use plain bearings, where rolling bearings are primarily used positive displacement compressors, which include reciprocating, scroll, and screw compressors. In this paper, we introduce main structure of compressor and bearing types, and required functions of bearings for screw type compressor, in which rolling bearings were used since the last half of 1950's in Japan, and the rolling bearing technology, which satisfies them.

2. Structures of common compressors and types of applicable bearings

Piston compressors use the action of a reciprocating piston to change gas volume (Fig. 2). Rolling bearings are used in this type of compressor for the crankshaft and the connecting rod, which support the piston. Deep groove ball bearings and cylindrical roller bearings are used for the crankshaft and the connecting rod, and needle roller bearings are used for the piston-pin.

Scroll compressors consist of two engaging spiral-

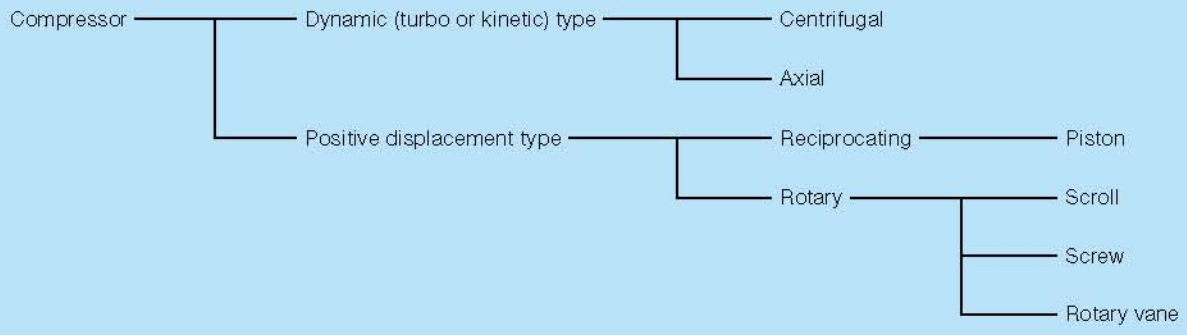

Fig. 1 Classifications of various types of compressors

shaped scroll members—one fixed and the other orbiting. The orbiting scroll traps pockets of gas that become compressed when the volume of the pockets decreases as the gas moves towards the center (Fig. 3). Cylindrical roller bearings and deep groove ball bearings are used for the main shaft. Matched angular contact ball bearings are used for the support shaft of the orbiting scroll.

Screw compressors include single screw designs and twin-screw designs. A single screw compressor consists of a screw rotor and two gate rotors that are positioned at right angles on the left and right sides of the screw rotor. Gas is compressed as the screw rotor groove engages with gate rotor gear.

A twin-screw compressor uses intermeshing male and female rotors (Fig. 4) to reduce the volume of trapped gas. Rolling bearings support both rotors. Cylindrical roller and needle roller bearings, which can accommodate expansion or contraction of the rotors as temperatures change, are primarily used as non-locating (float) position bearings to sustain radial loads on the suction side of the rotors. Matched angular contact ball bearings, tapered roller bearings, and combinations of cylindrical roller and angular contact ball bearings, which can accommodate axial loads, are used as locating (fixed) position bearings to sustain axial and radial loads on the discharge side of the rotors. Either oil or grease is used to lubricate the bearings depending on the needs of the application.

3. Main operating conditions of screw compressor bearings

Rotary screw air compressors can be classified according to the type of lubrication: oil and oil-free. Oil-cooled rotary screw compressors use oil in the compression chamber to both lubricate (cool) the rotary screws and seal the internal clearances. Oil-free rotary-screw compressors are

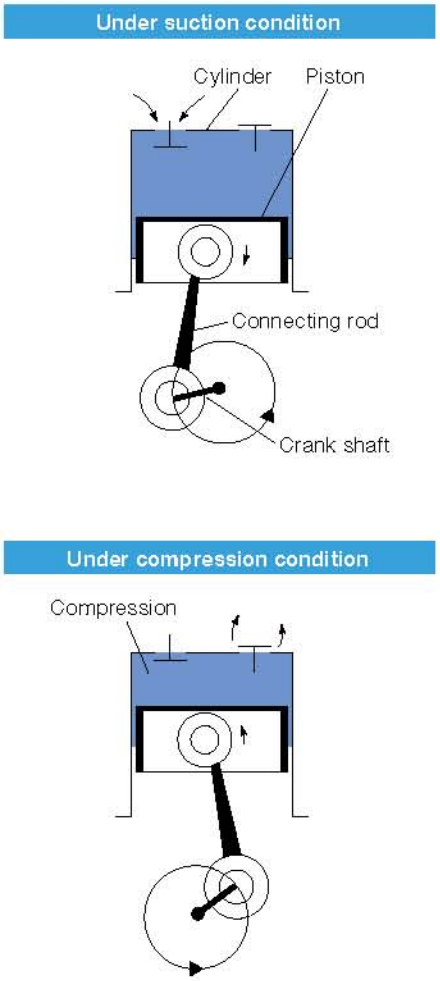

Fig. 2 Compression process of a reciprocating compressor

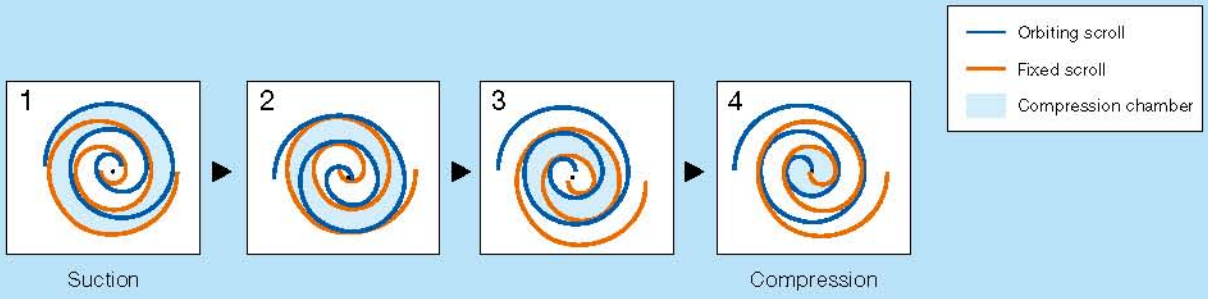

Fig. 3 Compression process of a scroll compressor

designed to compress air without oil in the compression chamber where a small clearance is maintained between the rotors. The rotors are driven by a gear arrangement that ensures the internal clearances. In addition, rotary screw compressors for refrigeration and air conditioning are classified as oil-cooled because refrigerant is mixed with oil inside the compression chamber.

Table 1 lists the main operating conditions of bearings—rotating speed and bearing load—used in rotary screw compressors. Width of the inner and outer rings of the locating (fixed) position bearings must be held to close tolerances to ensure the least amount of axial clearance. Any axial clearance between discharge end of the screw rotor shaft and rotor housing (Fig. 5) may lead to leakage and thus compromise compression efficiency.

4. Bearing technology for rolling bearing functionality

Rotary screw compressors require bearings that meet the performance requirements listed here.

4.1 High capacity

An air compressor must provide sufficient discharged air capacity, while a compressor for refrigeration and air conditioning must maintain sufficient refrigeration and cooling capability. This requires compressors with improved reliability and extended maintenance intervals. Therefore, high-capacity bearings are preferable if larger bearings are not to be used.

NSK has developed a high-capacity bearing series of the same basic dimension as a conventional bearing, but with optimal internal specifications that affect the size of rolling elements and cage design. The basic dynamic load rating of this high-capacity angular contact ball bearing series has been improved by 10 % to 20 % in comparison to conventional bearings. The basic dynamic load rating of the high-capacity cylindrical roller bearing series has been improved by 20 % to 50 %. Table 2 lists the main dimensions and basic dynamic load ratings of a typical

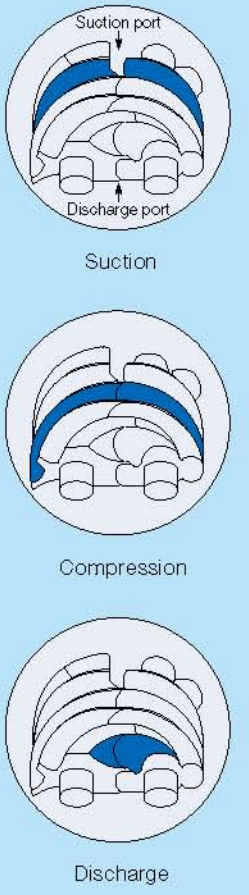

Fig. 4 Compression process of a screw compressor

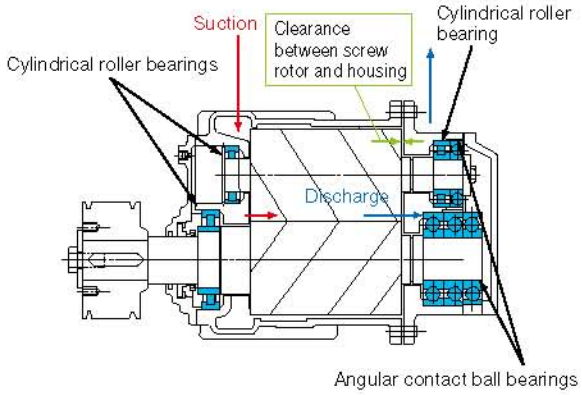

Fig. 5 Cross-section view of a twin-screw compressor

Table 1 Operating conditions of screw compressor bearing

	Oil lubricated	Oil-free
Rotating speed (rpm)	3 000 to 4 000	10 000 to 20 000
Load (N)	Normal (0.06 to 0.13 C_r)	Light (0.06 C_r or less)

C_r: Basic dynamic load rating

Table 2 Example of dimensions and basic load ratings of an angular contact ball bearing

	Bore diameter (mm)	Outside diameter (mm)	Conventional bearing (N)	High-capacity bearing (N)	Increasing rate (%)
7205	25	52	14 000	16 700	19
7305	25	62	22 900	25 900	13
7206	30	62	19 500	22 600	16
7306	30	72	29 100	34 500	19
7207	35	72	25 700	31 000	21
7307	35	80	34 500	38 500	12

bearing number for an angular contact ball bearing, which is normally used in the locating position. Fig. 6 illustrates a cross-section view of conventional and high-capacity bearings.

For example, the basic dynamic load rating of a conventional 7306 bearing (bore diameter: 30 mm; outside diameter: 72 mm) is 29 100 N. while the basic dynamic load rating of high-capacity bearing is 34 500 N. This reveals a 19 % higher rating than that of a conventional bearing. As a result, under given conditions of equal service life as a conventional bearing, this high-capacity bearing can sustain an approximately 19 % heavier load, or if the same load as that of a conventional bearing is applied, the high-capacity bearing offers an approximately 67 % longer service life.

In addition to higher capacity, bearing durability under conditions of exposure to refrigerant and refrigeration oil is required of bearings used in compressors for refrigeration systems and air conditioning. Here, cage durability is of key importance. Cages can be classified according to the type of material they are manufactured from: metal cages and resin cages. Cages used in compressor bearings require a manufacturing material that has good wear-resistant properties, and due to having a complicated design, the manufacturing material needs to be easy to process. Thus, resin cages hold a dominant position in respect to wear resistance since they have better self-lubricating properties than metal cages, and have a smaller friction coefficient. The cages used in these compressor bearings are primarily manufactured from polyamide 66 (PA66) resin.

The following sections discuss cage properties in greater detail.

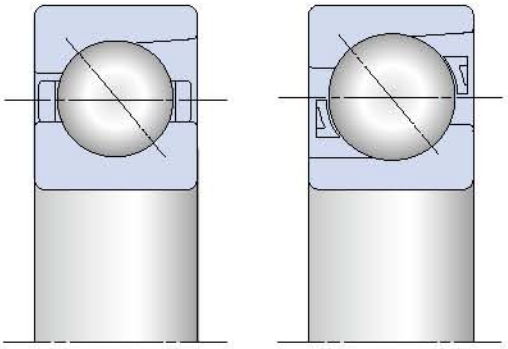

Fig. 6 Cross-section view of angular contact ball bearings

4.2 Wear-, oil-, and chemical-resistant properties of cages

Lubricating oil for compressor bearings also lubricates the compressor itself. The compression process subjects the lubricating oil to cycles of repeated heating and cooling. Gradually, the lubricating oil will deteriorate. In addition, lubricating oil for compressor bearings used in refrigeration systems and air conditioning is mixed with refrigerant, which reduces viscosity of the lubricating oil to extremely low levels. Under such conditions, the cage must maintain sufficient wear resistance. Furthermore, due to concerns over ozone depletion and environmental issues related to global warming, chlorofluorocarbons used in compressors continue to be replaced with alternative refrigerants, such as ammonia and carbon dioxide. As a result, base oils and additives are changed in the lubricating oil, which further requires that changes be made in the oil-resistant and chemical-resistant properties of the cage.

In order to solve these problems, NSK developed a proprietary linear polyphenylene sulfide (L-PPS) resin cage reinforced with glass fiber for use in compressor bearings. Features of the L-PPS resin material are further discussed here.

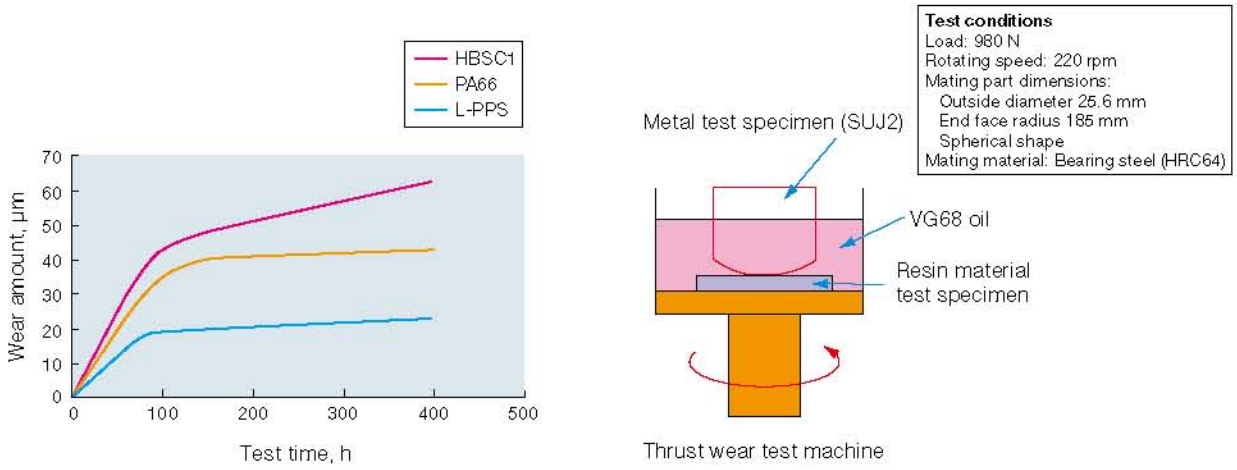

Fig. 7 Wear resistance of cage materials under oil lubrication

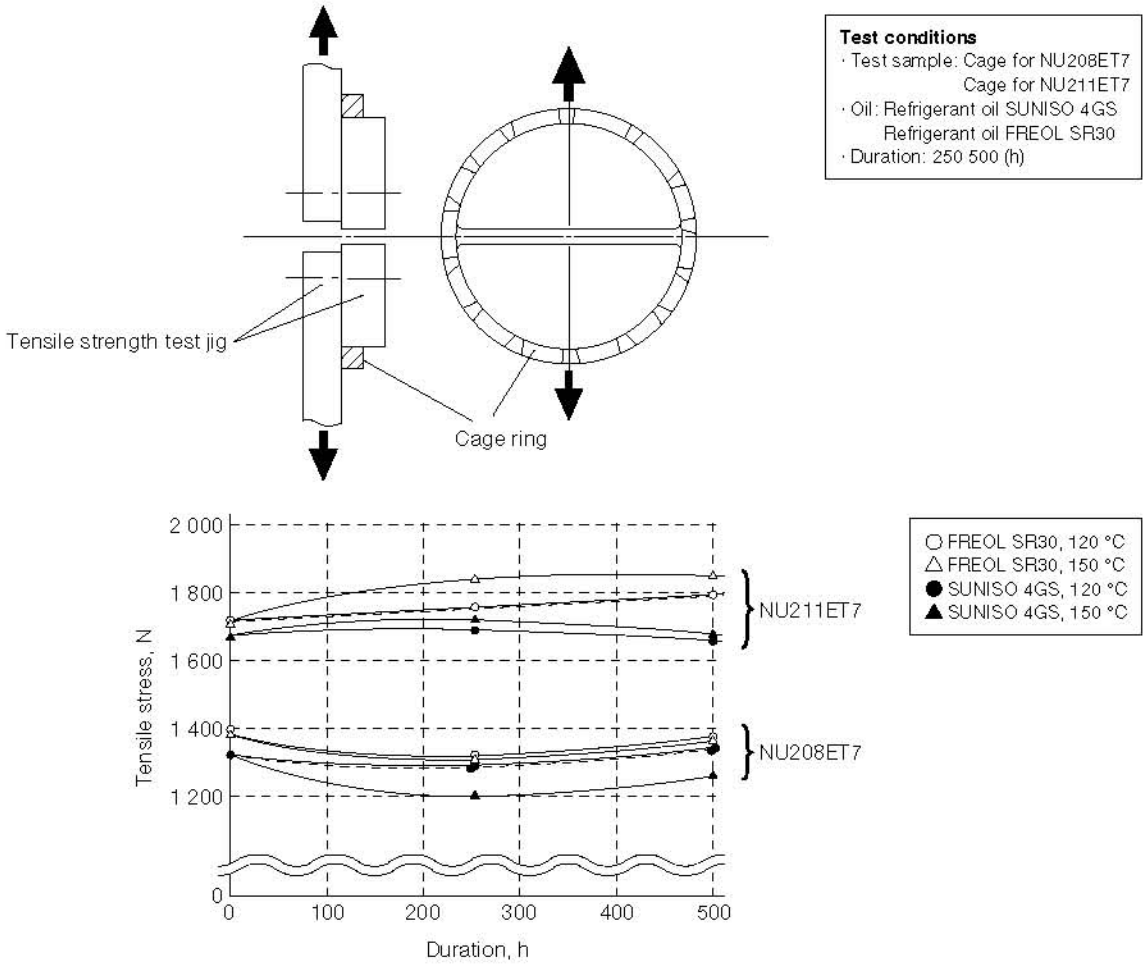

Fig. 8 Effect of high-temperature oil on cage strength[1)]

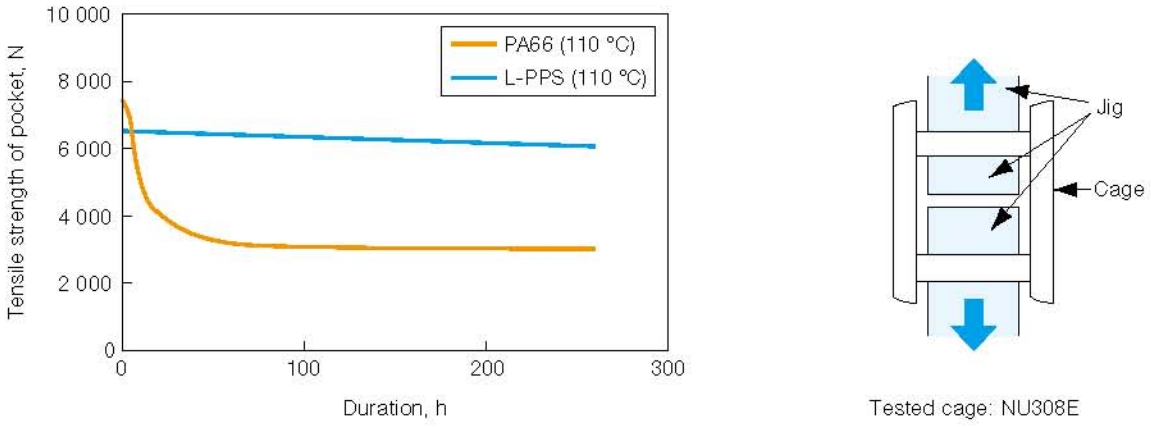

Fig. 9 Effect of ammonia gas on the tensile strength of cage pockets

4.2.1 Wear resistance

Fig. 7 illustrates varying degrees of wear resistance for three types of commonly used cage materials that were tested under oil lubricating conditions: HBSC1 (brass), PA66 resin, and L-PPS resin. Test results showed that the L-PPS resin material had the least amount of wear.

4.2.2 Oil resistance

Fig. 8 illustrates the strength of an L-PPS resin cage that was tested under high-temperature oil conditions. Tensile strength test results for the L-PPS resin cage show no appreciable deterioration after 500 hours of testing and that the cage maintained high chemical stability.

4.2.3 Chemical resistance

Cages made of PA66 resin, which are a common type of cage material, and cages made of L-PPS resin were mounted in NU308 cylindrical roller bearings and exposed to ammonia gas, which is a natural refrigerant used in refrigeration machines. Tests were then conducted to determine the tensile strength of the cage pockets. Test results shown in Fig. 9 reveal that the PA66 resin cage suffered a 60 % decline in tensile strength while the L-PPS resin cage remained relatively stable.

As described above, the L-PPS resin cage is superior in wear resistance, oil resistance, and chemical resistance—making it the most suitable cage material for compressor bearings.

5. ELCOMP bearing series

NSK has commercialized the ELCOMP Bearing series of compressor bearings for industrial machinery, which includes high-capacity angular contact ball bearings and cylindrical roller bearings with an L-PPS resin cage that is superior in wear resistance, oil resistance, and chemical resistance.

6. Postscript

This article has introduced the key functions that are required of rolling bearings from the standpoint of structure and the operating conditions of a screw compressor, and has introduced some of bearing technologies used to provide bearing functionality.

Air compressors, compressors for refrigeration and air-conditioning systems, environmentally friendly products, energy-saving technologies, high-performance products, and highly reliable products have been developed one after another. Advancements in NSK's proprietary technologies will continue to provide bearings that respond to the needs of future products on a timely basis.

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Shingo Higashi

Technological Trends of Ball Screws for Industrial Machinery

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ABSTRACT

Ball screws are used in an increasingly wider range of industrial applications in recent years. Such applications include injection molding machines where ball screws are required to perform under high-load and high-speed operating conditions at low-noise levels. This article introduces various series of ball screws, including the A1 series used for the injector ram (reciprocating screw) and clamping unit of electric injection molding machines. This series has been designed for high-speed operations at low-noise levels in a low-profile package, which also makes the series compatible with material handling equipment and robots as well. This article will also cover the high performance seals used in this series to protect the ball screw from various contaminants.

1. Introduction

Ball screws were put into practical use for automotive steering systems in the United States during the 1950s. From 1961, NSK started manufacturing and delivering precision ball screws for use in machine tool applications.

In recent years, ball screws have been required to operate at higher speeds, lower noise levels, and be more compact in order to meet the demands of multifunctional industrial machinery.

Accordingly, NSK developed a high-capacity series of ball screws for use in electric injection molding machines. This high-capacity series established NSK as a leader in the market of ball screws for use in high load applications.

All-electric machines have rapidly increased their share of the Japan market. Consequently, there is a growing demand for high-capacity ball screws for use in large injection molding machines, and ball screws for high-speed injection, which facilitates thin-wall molding. Additionally, the number of other high-load applications is increasing, which include electrically driven aluminum die-casting machines, presses, and powder molding machines. Ball screws used in these applications must also be developed to optimally meet the specific needs of each application.

There have been remarkable developments in the area of mechatronics that are used in the equipment for manufacturing semiconductors, liquid crystal display panels, robots, and more. NSK has been designing ball screws that meet the new demands of such newly developed manufacturing equipment. Additionally, many specialized ball screws can now be found operating in equipment for aerospace and aviation applications, where they must meet the critical demands of such unique environments.

This article describes the recent technological trends of ball screws used in industrial manufacturing equipment, which include high-capacity ball screws and ball screws for robotic handling and transfer systems, and high performance seals.

2. High-capacity ball screws

Conventionally, hydraulic presses have been used in applications requiring high linear pressing force. In recent years, however, there has been a shift towards using all-electric presses that consist of a ball screw and a motor due to superior energy savings, low environmental impact, and longer maintenance intervals. High-capacity ball screws that are used to replace hydraulic systems must perform a wide range of functions, which include operating conditions that are quite different from those of a conventional ball screw application, such as continuous operation with short strokes. Therefore, ball screws require a design that is specifically tailored to meet the needs of each application.

Here, we will introduce recently developed ball screws for use in high-capacity applications.

2.1 Ball screws for injection molding machines

In the past, hydraulic systems were the primary source of press force in conventional injection molding machines. From the mid-90s, all-electric machines started to increase in number due to various benefits and higher functionality including less power consumption, ease of maintenance, and greater control performance. Fig. 1 shows the number of differing types of injection molding machines that were exhibited at previous International Plastic Fair (IPF) shows. In 1999, all-electric injection molding machines on display stood at 60 %. By 2005, 88 % of the machines on display were all-electric models. If you include the hybrid machines, which use a combination of hydraulic pumps and servomotors, then the ratio of machines that require ball screws stands at 95 %.

2.1.1 Features of ball screws for injection molding machines

The illustration in Fig. 2 shows where ball screws are used in a typical injection-molding machine.

The development of NSK's HTF series of high-capacity ball screw became a market leader after its introduction

to the marketplace in 1996. The HTF series featured improved dynamic load and static load ratings, was made available in a compact size, and offered a longer service life.

(1) Optimum design for high-capacity applications uses balls with larger diameter in respect to shaft diameter and lead.
(2) Specifications of the recirculation circuit and the ball groove profile/geometry have been changed to accommodate the large-diameter balls.
(3) Positioning and design of the recirculation circuit has been modified to more evenly distribute load among the balls.
(4) The outer diameter of the nut has been changed to provide greater balance in relation to the shaft.
(5) The S1 ball retainer is provided as standard equipment to improve ball nut durability as a measure against unbalanced loads.

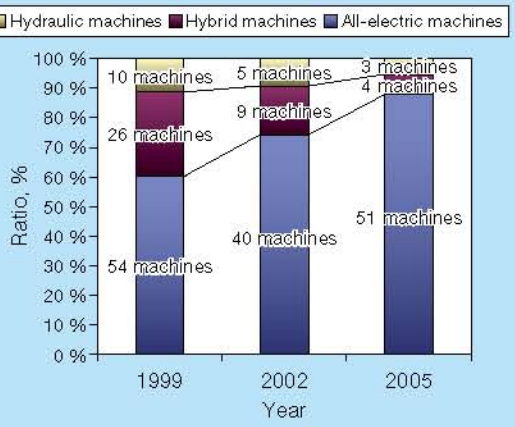

Fig. 1 Three basic types of injection molding machines on the market

The use of all-electric injection molding machines in Japan was initially limited to smaller machines with a clamping force of 150 tons or less. Recently, there is growing demand for ultra-large machines with a clamping force of up to 3 000 tons. NSK supplies ball screws with large diameter balls for these applications.

There are also demands for injection molding machines that can operate at high speeds to produce ultra-thin and highly precise molded parts for components used in IT-related equipment and devices. Such applications require high-speed ball screws for the mechanism that opens and closes the mold to improve productivity. NSK has developed several new products to meet the needs of newer injection molding machines. Details of these products are described below. Additionally, features are summarized in Fig. 3.

2.1.2 High-speed ball screws for injector rams

NSK developed and commercialized the HTF-SRC series of ball screws, (Photo 1) which are able to operate at high speeds and low noise. Such features were made possible by adopting a newly developed smooth-return coupling (SRC) for the recirculation circuit while the conventional HTF series uses a conventional tube-type recirculation circuit. The speed limitations of a conventional recirculation circuit are determined by the strength of the pick-up tongues at both ends of circuit. The SRC recirculation circuit adopts plastic molded parts that smoothly pick up balls as they exit the loaded zone of the groove and enter the recirculation circuit tube in a three-dimensional

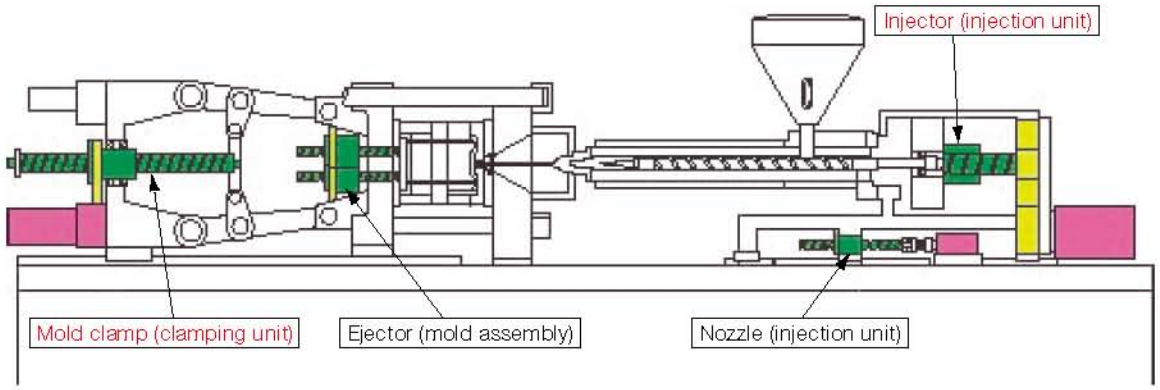

Fig. 2 Areas where ball screws are used in all electric injection-molding machines

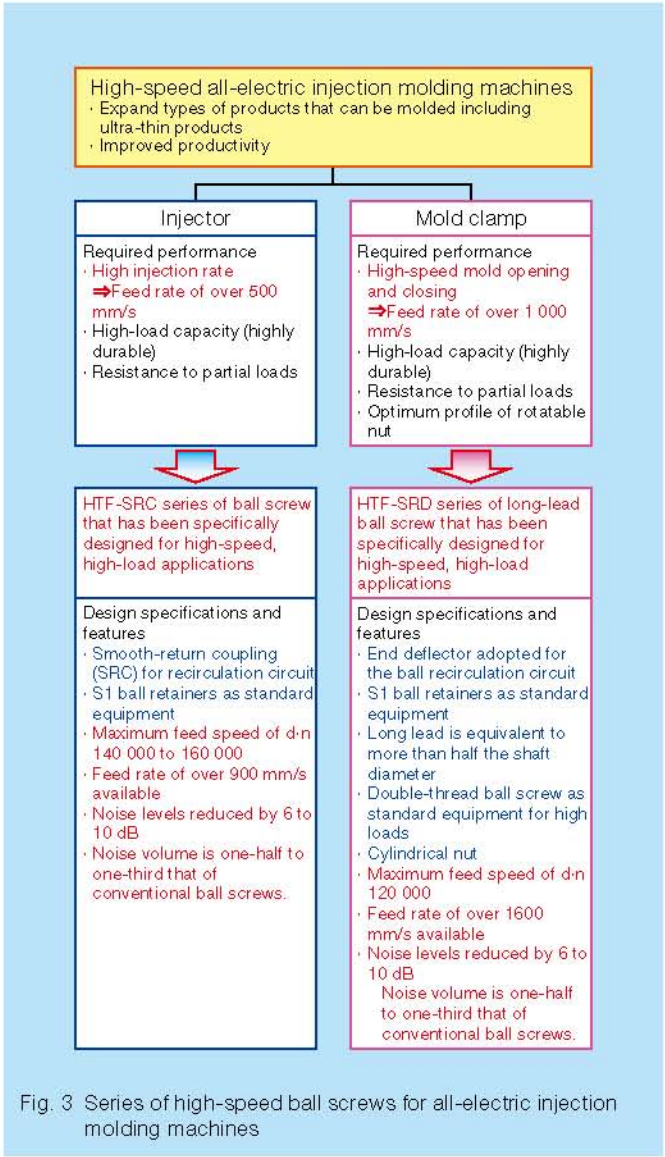

Fig. 3 Series of high-speed ball screws for all-electric injection molding machines

path that connects smoothly with the spiral of the ball groove. With an SRC, the HTF-SRC series can achieve a maximum speed ranging from d·n 140 000 to 160 000 (shaft diameter d [mm] × revolutions n [rpm]) (Fig. 4). For reference, the range of d·n value for a standard product is from 70 000 to 100 000. This enables a feed rate of over 500 mm/s. Noise level is reduced by 6 dB to 10 dB in comparison with conventional ball screws. Also, noise volume is one-half to one-third that of conventional ball screws.

In order to improve durability in response to unbalanced loads, the HTF-SRC series uses S1 ball retainers as standard as does the conventional HTF series.

2.1.3 High-speed ball screws for mold clamps

Because even higher speeds are required for the mold clamps in comparison to the injection ram, a new series of ball screws was developed and introduced especially for this application. The following section discusses ball screws for the mold clamp.

Photo 1 HTF-SRC series

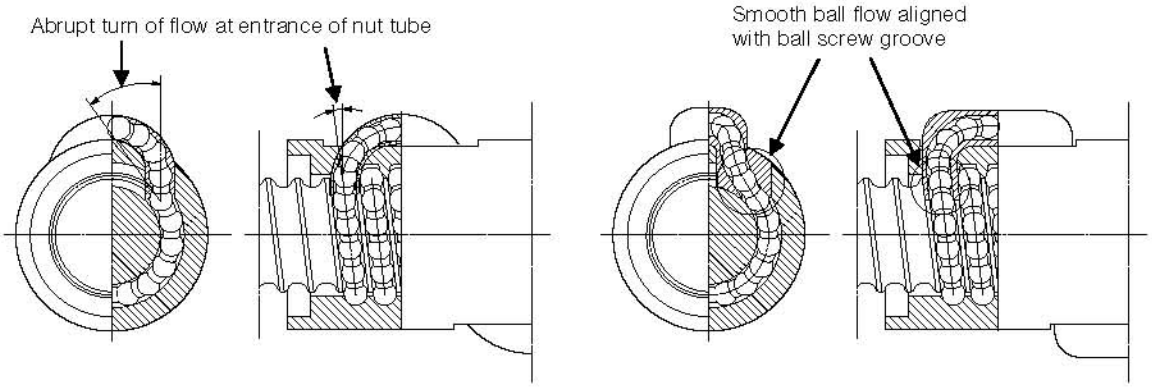

Fig. 4 Comparison of a conventional and SRC ball screw recirculation circuits

Many mold clamps adopted a booster and toggle clamp mechanism. Therefore, the stroke was longer than that of the injection ram. A faster speed of over 1 000 mm/s was required in order to improve productivity.

For these reasons, NSK developed and introduced the HTF-SRD series of ball screws (see Photo 2) for use with mold clamps. Specifications of this series are provided below.

(1) Adopts an end deflector in the ball recirculation circuit, which is most suitable for high-speed applications.
(2) Provided with a long lead that is half or more of the shaft diameter for facilitating high-speed operation.
(3) Uses a double-thread ball screw as standard equipment for accommodating high loads.
(4) Uses a cylindrical nut that is configured to facilitate easier mounting in an application.
(5) Uses the S1 ball retainers as standard equipment—the same retainers that are used in conventional high-capacity ball screws.

These specifications enable rapid feed rates exceeding 1 200 mm/s. Additionally, noise levels have been reduced by 6 to 10 dB and noise volume has been reduced by one-half to one-third that of conventional ball screws.

2.1.4 Less grease used and cleaner operations

Injection molding machines have an automatic grease replenishing system that feeds a continuous supply of grease to the ball screw to ensure durability. Non-contact seals are typically installed at both ends of the nut to prevent overheating. Therefore, the replenished grease easily flows through the clearance between the seals at both ends of the nut. This has created new problems: grease is wasted and needs to be replaced; and the excess grease contaminates the equipment and working environment.

NSK addressed these problems with the development and introduction of the A1 series of ball screws, which use grease lubrication with contact seals. The technology used in the A1 series is based on NSK's V1 series ball screw, which already enjoys a favorable reputation in the marketplace. The A1 series retains grease in the nut and prevents any grease from remaining on the shaft, which tends to splash during shaft rotation.

Photo 2 HTF-SRD series

2.2 Other high-load applications

In addition to injection molding machines, demand for other high-load applications using ball screws, which includes all-electric presses and powder molding machines, has increased remarkably.

With respect to all-electric presses, ball screws are already used in applications rated at 5 tons or less. Presses rated at several hundred tons, however, have only recently started to use electrical motors. While there are simple presses that perform press fitting, punching, or bending processes, highly functional presses that perform precise positioning control with servomotors and ball screws have been increasing.

At present, NSK proposes to clients that they use the ball screw that is chosen by NSK, basically from the HTF series, HTF-SRC series, or the HTF-SRD series of ball screws, as the optimum ball screw for matching the operating conditions of a given application.

In the future, demand for ball screws that can accommodate more rapid acceleration and deceleration cycles, shorter strokes, and shorter cycle times will increase, in addition to high-speed and high-load operating conditions.

3. Ball screws for handling and transfer systems

High-speed operation of equipment in handling and transfer systems has been remarkable in recent years as manufacturers aim for improved productivity. Thus, the number of ball-screw-driven handling and transfer systems being put to use is also increasing.

If you simply increase rotational speed to gain high speed, you will end up with excess noise and vibrations. NSK has, however, commercialized series of ball screw that is capable of both high-speed operations and quiet-running performance.

3.1 High speed

In a conventional ball screw recirculation circuit, the balls suddenly cease to roll smoothly at the entry point of the unloaded zone when they are picked up from the screw grooves into the recirculation component and vice versa at the exit point of the unloaded zone. If speed is increased drastically, high loads are applied at the entry and exit points, which can cause some reliability problems. For example, in a ball screw that uses a tube-type recirculation circuit, the balls roll along the screw groove under load. When the pick-up tongues at both ends of the recirculation circuit pick up the balls, the balls change direction and collide with the pick-up tongue as they are directed into the recirculation circuit. Thus, rotational

speeds of a ball screw have been limited by the strength of the recirculation circuit components.

To address this issue, NSK developed the BSS series of ball screws that uses a new end-defector type of recirculation circuit that is capable of accommodating high-speed rotation (see Photo 3). This new type of recirculation circuit can smoothly pick up the balls from the screw groove, which reduces the load on the recirculation circuit components at the entry and exit points. Thus, the BSS series can operate at 1.6 times the rotational speed of a conventional ball screw.

3.2 More compact with less noise and vibration

It is impossible to fully prevent the noise and vibrations that are generated at the entry and exit points of a recirculation circuit in a ball screw due to the flow of balls being suddenly interrupted. Furthermore, if the ball screw is rotated at higher speeds, the noise and vibrations will only increase. The origin of all this noise and vibration is mostly at the entry and exit points of the recirculation circuit where the balls collide with recirculation circuit components and create vibrations.

Because the end-deflector recirculation circuit is able to smoothly pick up the balls from the ball screw groove, the previously mentioned collision between balls and components is significantly reduced, which results in less noise and vibration. In fact, noise levels can be reduced by 5 to 7 dB in comparison with conventional ball screws of the same specification.

Additionally, using an end-deflector recirculation circuit makes it possible to reduce the outer diameter of the nut by 20 % to 30 %. Thus, with development of this new recirculation circuit, we were able to achieve higher rotating speeds, quieter running performance, and reduce the size of components for use in compact applications.

Photo 3 BSS series

4. Highly resistant against debris

Ball screws are used in a wide range of applications that subject the screws to various operating conditions where they risk exposure to all kinds of debris, including processed metal, ceramics, rubber, sawdust, weld slag, and spatter from welding contact tips.

The following risks may arise if the nut interior becomes contaminated:

(1) Premature wear of ball grooves and balls, resulting in premature loss of preload.
(2) Foreign matter gets crushed between the balls and the screw grooves, which generates scratches on the groove and ball surfaces, which thus trigger fatigue flaking.
(3) Foreign matter jams the balls in the recirculation circuit, which damage circuit components.
(4) Some foreign matter can absorb the lubricant resulting in improper lubrication, generation of rust, and excessive temperature rise.

In order to prevent such foreign matter from entering into the nut, conventional ball screws had non-contact labyrinth seals or wiper seals that were mounted at both ends of ball screw nut and tightened in the radial direction. However, sealing performance was insufficient with this approach. Furthermore, wiper seals tended to overheat under high-speed operations due to seal contact torque.

Therefore, there was growing demand from the market for a seal that was highly resistant to debris, performed with low sealing torque, and was suitable for high-speed applications. NSK responded by developing the V1 series of ball screws with high performance seals to meet these demands. Fig. 5 illustrates the structure of the seal that is used in the V1 series.

Features of the V1 series are as follows:

(1) The seal lip profile features a small contact area.
(2) The seal is mounted with NSK's K1 lubrication unit as standard equipment, which improves lubrication performance and durability by lubricating the seal lip portion.
(3) Compatible with applications operated at speeds of up to d·n 150 000.

As a result, ingress of foreign matter was reduced to 1/15 that of NSK's conventional product, and durability under conditions of fine powder debris (iron oxide) contamination has increased by fourfold. Additionally, the small amount of seal friction torque greatly facilitates high-speed operations.

5. Conclusion

Ball screw applications for industrial machinery include a wide range of products that are too many to name. In this article, we have limited our focus to recent trends. There are many special-specification ball screws for various applications including manufacturing equipment for semiconductors, aerospace applications, and many more. We hope to discuss the use of ball screws in these applications in a future article.

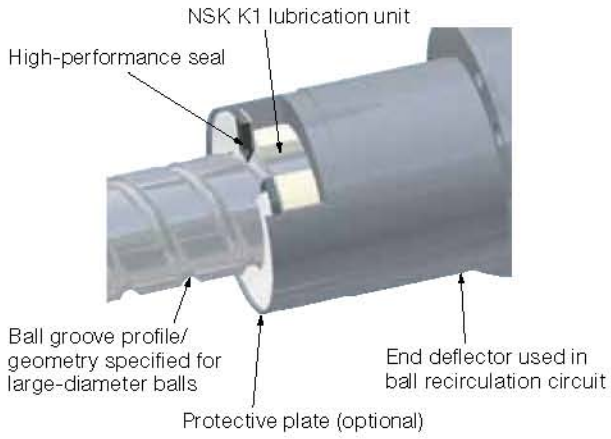

Fig. 5 Cutaway view of ball screw nut

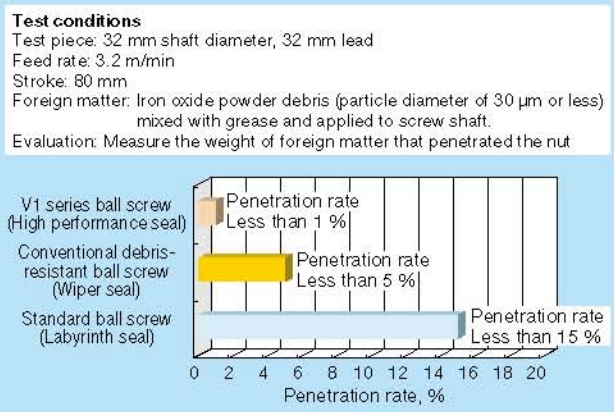

Fig. 6 Particle penetration rate test results

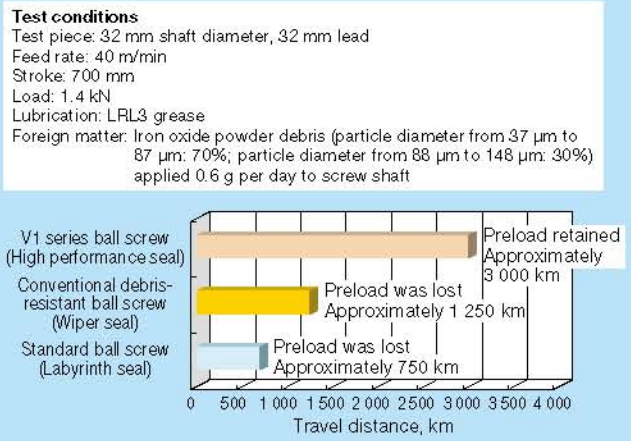

Fig. 7 Extreme durability test results using iron particles

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Masanori Ito

Technological Trends of NSK Linear Guides for Industrial Machines

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ABSTRACT

The basic configuration of linear guides (linear motion rolling bearings with a rail) in use today can be found in a 1932 French patent. In the first half of the 1980s, NSK manufactured precision linear guides on a commercial basis mainly for machine tools. Later, NSK developed various linear guides that met the needs of specific applications or the needs of the market. This article introduces recent technological trends of linear guides. We will discuss new technologies and new products including the RA series of NSK roller guides.

1. Introduction

In ancient times, transporting a large stone across land was achieved by pulling the stone block over transverse logs that rolled underneath. At the beginning of the 20th century, rolling linear guides applied the same principle to mechanical applications. Linear guides initially consisted of ball splines that were used in industrial machinery. Although a variation of this design was originally patented in France in 1932, it was not until the 1970s that linear guides were commercialized.

As numerically controlled (NC) machine tools became more advanced, conventional sliding guides caused the problems relating to durability, and hindered the high-speed and highly accurate performance potential of NC instruction. Rolling guides, however, became an effective solution to the problems posed by sliding guides. Rolling guides offered high-speed performance and were compatible with electronically controlled applications. Thus, development of machine tools has thus been advanced with the use of rolling guides. Additionally, the use of rolling guides in electronic component and semiconductor manufacturing equipment has also become widely spread as developments in such equipment continue to advance.

NSK focused on machine tool makers and commercialized the LY series of precision linear guides in the early 1980s. NSK then developed products that responded to the various needs of the marketplace. At the same time, performance requirements of rolling guides advanced on a daily basis. Such requirements included the capability to withstand harsh operating environments where guides are exposed to foreign matter, higher rigidity, higher loading capacity, and improved motion accuracy. NSK thus addressed these needs by developing new linear guides. Here, we will discuss the various technologies that NSK developed for linear guides in order to meet a diversity of needs.

2. Responding to advancements in machine tool technology

2.1 From sliding guides to rolling guides

In the 1980s, machine tool makers shifted from using sliding guides to rolling guides. Whereas the amount of frictional force that is generated in a sliding guide is very different from that of a rolling guide, many users were concerned about the vibration-damping capability of rolling guides when they were first used in machine tools.

Set against this backdrop, NSK developed the LY series of linear guides for machine tools. The LY series adopted a proprietary offset gothic-arch groove design, which achieved high rigidity with preload using a four-point contact structure (two contact points on the rail and two contact points on the ball slide). While this four-point contact structure results in a larger frictional force, it also filled a role of damping vibrations from the table, and provided a suitable degree of performance for machine tools of that time.

2.2 High-load capacity and highly rigid

Rolling guides have been commonly used with machine tools since the 1990s. During that time, the high-speed performance and rapid acceleration and deceleration cycles of machine tools advanced with developments in NC technology. Machine tool feed rates have nearly doubled in the past decade. As a result, the required travel life (travel of a specified distance) has increased twofold, and accordingly, users demand ever-higher load capacity. Additionally, trends toward higher speeds, more rapid accelerations are performed to shorten running time--even for short strokes. Therefore, higher rigidity has also become paramount. Whereas machine tool rigidity is highly influenced by linear guidance systems, demand grew for rolling linear guides with higher rigidity.

Moreover, high precision was promoted together with the advancement of numerical control technology, and the contour precision of machine tools, such as follow-up accuracy, became an increasingly important feature. Frictional force of the LY series was intentionally increased as a feature to enhance damping performance.

Photo 1 RA series of NSK roller guides

However, this feature impacted follow-up accuracy, resulting in demand for products with less frictional force. Based on these demands, NSK commercialized the LA series of linear guides, which has six grooves on the rail for use with machine tools. Fig. 1 shows cross-section views of the standard LY series and the LA series of linear guides. The LA series featured six ball grooves, a 50 % to 60 % reduction in frictional force, and rigidity and capacity that had been increased 1.5 to 1.6 times higher than that of the LY series, which was achieved through the use of two-point contact and four-point contact arrangements. As was the case with the LY series, the newer LA series enjoyed a favorable reputation among machine tool users.

Roller guides are commonly used since the spread of linear guides spread throughout Europe due to rollers being more effective than balls in providing higher load capacity and higher rigidity. NSK developed and commercialized the RA series of roller guides (Photo 1) in 2004 in anticipation of the progression of demand for higher operating speeds and more rapid acceleration and deceleration cycles. NSK fully applied proprietary analysis technologies in developing the RA series, which consequently, offers unprecedented rigidity and loading carrying capacity. Table 1 lists a comparison of load capacity and rigidity of the LY series, the LA series, and the RA series.

2.2.1 Technology for high load-carrying capacity in a roller guide

Load-carrying capacity, which is a combination of the basic dynamic load rating and the basic static load rating of a roller guide, is heavily influenced by the diameter of the rolling elements (rollers). This is also true for linear guides using balls for the rolling elements. Additionally, increasing the effective length of a roller can also enhance load-carrying capacity. NSK applied this concept toward development of a roller that was larger than the conventional series (Photo 2) and made more effective use of the slide's interior space. A unique roller retaining structure was developed and the rollers were designed to have an optimal roller end face profile (crowning shape). Combined, these efforts resulted in a roller guide with high load carrying capacity. Fig. 2 compares the basic dynamic load rating and basic static load rating of an NSK roller guide and a competitor's roller guide. (Some manufacturers calculate the basic dynamic load rating using proprietary methods, but NSK performs calculations based on ISO-14728-1 and ISO-14728-2, which are based on actual data.) The RA series of roller guides can provide higher basic load ratings than that of a conventional roller guide.

2.2.2 Technology for highly rigid roller guides[2)]

Because rollers have extremely higher contact stiffness with the raceway surface in comparison with balls, they can achieve a greater degree of stiffness in a linear guide. Due to this high contact stiffness, deformation of the slider (carriage) significantly influences stiffness of the entire application. The inverted U-shape of the slider deforms under roller contact forces acting on the inner

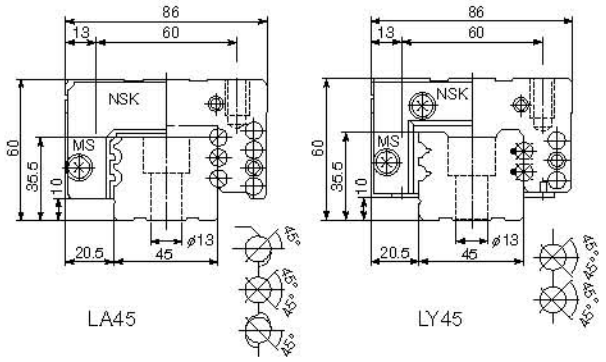

Fig. 1 Cross-section views of the LY and LA series of NSK linear guides[1)]

Table 1 Comparison of capacity and rigidity of NSK linear guides for machine tools

	LY45 ultrahigh load with Z4 preload	LA45 ultrahigh load with Z4 preload	RA45 ultrahigh load with Z3 preload
Basic dynamic load rating, N *	65 500	88 000	116 000
Basic static load rating, N	151 000	197 000	305 000
Rigidity, N/μm **	1 100	1 640	2 740

Notes:
* Basic dynamic load rating is unified at 100 km rating.
** Rigidity is a theoretical calculation for reference purposes.

sides of the slider. As contact between the roller and the slider changes, linear guide stiffness deteriorates. In developing the RA series, we addressed this loss of rigidity by calculating the amount of slider deformation through FEM analysis and determined the optimal contact conditions between rollers and the slider under contact force (preloading for calculation purposes). Applying these analysis results aided in development of a linear guide that performed with an extremely high degree of contact rigidity. Additionally, the number of holes on the slide unit for mounting bolts was increased from four (LA series) to six. The number of holes on the rail for mounting bolts was increased to twice that of the LA series. These modifications further increase rigidity after being mounted in a real-world application. Fig. 3 illustrates the results of numerical simulation using FEM analysis on the slide unit.

Fig. 4 shows a comparison of actual rigidity of the RA series roller guide and a competitor's brand of roller guide. The RA series shows that it can achieve high rigidity through the full application of analysis technology.

3. LCD panel manufacturing equipment

Liquid crystal display (LCD) panel manufacturing equipment, which includes spin coaters that are used to deposit photoresist, require a linear guide that provides a sufficiently high degree of motion accuracy to ensure an even deposit of photoresist. In such an application, hydrostatic guides used to be the norm due to inaccuracies of linear guides. However, hydrostatic guides are expensive and are less capable of damping unwanted vibrations. Therefore, there was high demand for a linear guide using rolling elements that was able to achieve accuracy on a par with a hydraulic guide.

3.1 Motion accuracy

Motion accuracy of a linear guide is generally influenced by the accuracy of the guide's mounting surfaces and the degree of accuracy used when manufacturing the guide's rail. However, it has been difficult to develop a linear guide that achieves motion accuracy that is equivalent

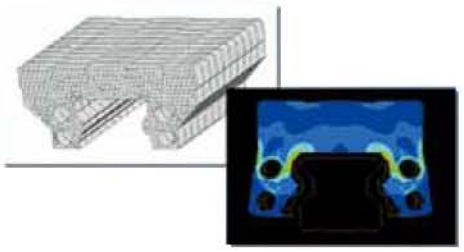

Fig. 3 FEM model of a slider, and the analysis results of slider deformation[3]

Photo 2 Comparison of rollers[2]

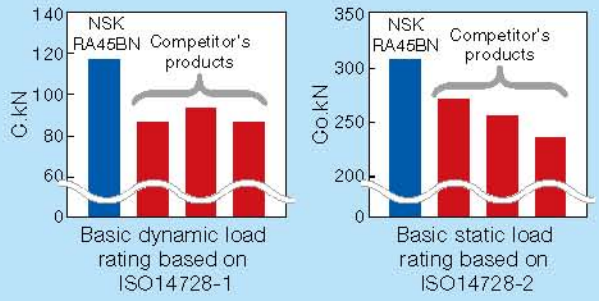

Fig. 2 Comparison of load rating (size #45)[2]

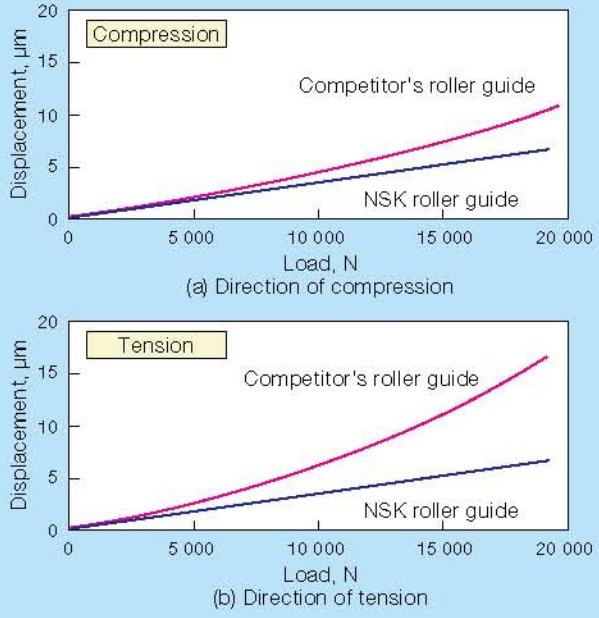

Fig. 4 Comparison of actual rigidity of roller guides (size #45)[3]

to that of a hydraulic guide due to limitations in the accuracy of rails and mounting surfaces of the linear guide structure itself.

Fig. 5 shows an example of measuring the motion accuracy of a linear guide. As shown in the figure, there are two primary factors affecting motion accuracy. One factor is the transit vibration of the roller, which equates to twice the diameter of the roller. The other factor is the rail mounting bolt pitch. At NSK, the transit vibration equating to twice the diameter of the roller is referred to as rolling element passage vibration.

3.2 Technology for high accuracy

Rolling element passage vibration is a phenomenon that occurs under conditions of displacement (linear or angular) of the slide unit in any direction of the five degrees-of-freedom (DOF). Five DOF displacement of the slide unit is in relation to the rigidity of the slide and changes in load distribution of the rolling elements on the raceway surface (Fig. 6). NSK successfully developed quantitative analysis of this rolling element passage vibration, which was made possible using an equation of motion that takes load balance and moment balance of the internal and external loads and calculates the amount of linear displacement or angular displacement in each direction of five DOF motion. Thus, using this quantitive analysis, the level of rolling element passage vibration can be estimated based on linear guide specifications, including the end profile of the slide raceway (crowning profile) and table layout information.

The level of rolling element passage vibration is influenced by the amount of preload and the number of rollers. However, based on the quantitive analysis previously discussed, we found that the most influential factor was the number of rollers in the loaded zone, or in other words, the length of slider and the crowning profile of the raceway end (see Fig. 7).

Conversely, the factor of rail mounting bolt pitch is considered to generate minute rail deformations when the mounting bolts are tightened. So, we conducted FEM analysis on the deformation resulting from tightened mounting bolts, and investigated the structure of the mounting holes in order to reduce the amount of related deformation (Fig. 8). As a result, we were able to develop a

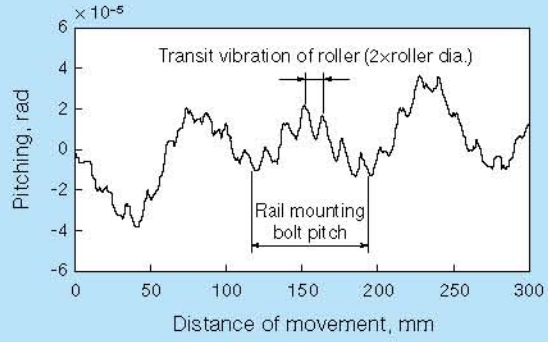

Fig. 5 Motion accuracy of an NSK linear guide[5]

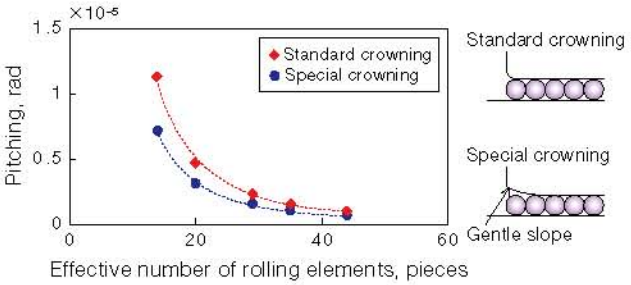

Fig. 7 Relationship between profile of slider crowning and calculated rolling element passage vibration[3]

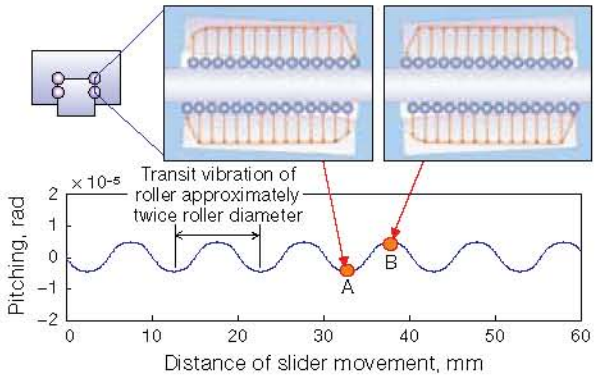

Fig. 6 Mechanism of rolling element passage vibration[3]

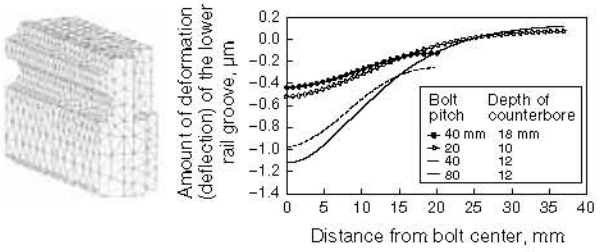

Fig. 8 FEM model of a rail, and analysis results of rail deformation[5]

Photo 3 High-Accuracy series of NSK linear guides

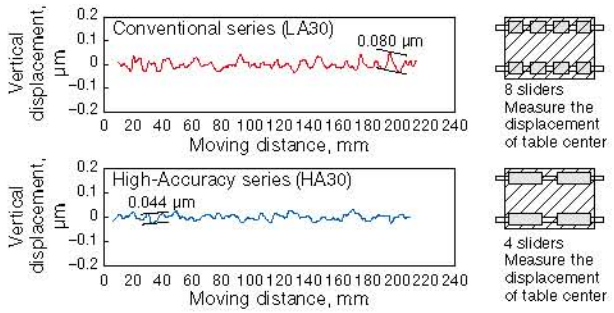

Fig. 9 Vibration level comparison of rolling element passage (size #30 under medium preload)

mounting hole profile that maintained the effectiveness of a mounting bolt while minimizing rail deformation.

Based on the above analysis results, NSK developed the High-Accuracy series of linear guides (Photo 3) for highly precise applications. This highly accurate series features significantly less rolling element passage vibration, which was achieved using sliders that have twice the length of a standard slider and have raceways with specialized curves (crowning) at both ends of the slider raceways. Additionally, measures were taken to minimize deflection of the rail, which include shortening by half the distance between each rail mounting bolt hole and providing greater counterbore depth of each hole. As a result, vibrations in the High-Accuracy series, which are caused by rolling element passage and adversely affect motion accuracy of the table itself, were reduced to approximately half that of conventional series. In fact, vibration levels were reduced to approximately 40 nm (Fig. 9). The High-Accuracy series of linear guide is currently being used in the field in place of hydrostatic guides for LCD panel and semiconductor manufacturing equipment. This series is also used with highly precise machine tools, including high-precision lathes and grinding machines.

4. Responding to new applications and demands

4.1 Environments of foreign matter

Where linear guides used in tire manufacturing equipment are exposed to rubber particles, linear guides used in woodworking machinery are exposed to sawdust. Fine rubber particles or sawdust quickly damage a linear guide after ingression or being absorbed by the lubricant. Therefore, measures are taken, which include the use of bellow covers, to establish a physical barrier between debris and the linear guide.

However, the use of bellow covers to protect linear guides has been ineffective in environments where minute particles can drift past the cover or where debris is so large and heavy that the bellow cover proves impractical. Furthermore, there are cases where a bellow cover cannot be installed due to equipment configuration or space limitations. Therefore, there was growing demand for a linear guide that offered significantly higher resistance to fine particles and debris under contaminated operating conditions.

In response, NSK developed a high-performance end seal (Fig. 10) featuring a lip-type design that significantly reduces entry of contamination and increases service life in comparison to conventional seals. Moreover, NSK developed and commercialized a highly debris-resistant V1 series of NSK linear guide that adopts this high-performance end seal. Consequently, the V1 series achieved longer life when operated in contaminated environments where the rail was exposed directly to debris. Photo 4 illustrates how effectively the V1 series wiped off foreign matter that had adhered to the rail. After the V1 slider passed along the rail, debris that had adhered to the rail was clearly wiped off. Next, Figs. 11 and 12 show test results that confirm durability of the V1 series in such contaminated environments. Test results in Fig. 11 represent exposure to rubber particle contamination, and the results in Fig. 12 represent exposure to fine sawdust contamination. The test results illustrate that service life of the V1 series was extended by more than five times under rubber particle contaminated conditions and more than two times under fine sawdust contaminated conditions.

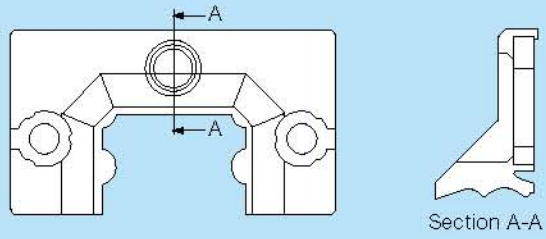

Fig. 10 High-performance end seal[7]

Before slider passes　　After slider passes

Photo 4 Foreign matter on a V1 series rail of NSK linear guides before and after being wiped off by the slider

Test conditions

Test sample	VH30
Test posture	Horizontal (wall mounting)
Feed speed	500 mm/s
Lubrication	Grease (prelubricated at initial stage only)
Foreign matter	Rubber particles

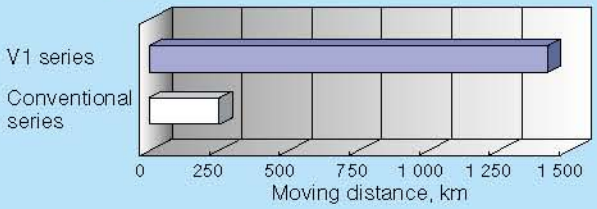

Fig. 11 Durability test results under rubber particle contaminated conditions[7]

Test conditions

Test sample	VH30
Test posture	Horizontal (wall mounting)
Feed speed	400 mm/s
Lubrication	Grease (prelubricated at initial stage only)
Foreign matter	Fine sawdust

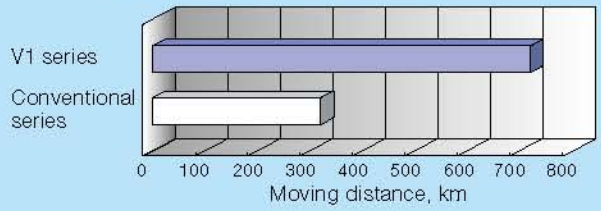

Fig. 12 Durability test results under fine sawdust contaminated conditions[7]

Photo 5 Linear guide with NSK K1 unit for food processing equipment and medical equipment

The V1 series of linear guide offers users excellent performance in contaminated environments and has been widely adopted for use in applications including woodworking machinery, graphite milling machines, tire buffers, laser-cutting machines, and applications that are operated under harshly contaminated conditions such as a welding line.

4.2 Safety

Applications using linear guides have expanded in recent years to include food processing equipment and medical equipment. Such equipment must ensure that there is no splashing of lubricants in addition to meeting other stringent requirements that the food and pharmaceutical industries put in place to negate any possibility of lubricant ingestion or food contamination.

NSK thus developed the NSK K1 lubrication unit in order to meet the needs of related food processing equipment and medical equipment. The K1 lubrication unit has been approved by the US Food and Drug Administration (FDA) for use in food processing equipment and medical devices, and complies with food safety standards set forth by the Japan Food Sanitation Act. NSK K1 lubrication units (see white component in Photo 5) are available on NSK linear motion components, including linear guides.

In addition to featuring refined materials that conform to strict standards set by the FDA for use in food processing equipment and medical devices, the K1 lubrication unit also provides long-term maintenance-free performance.

5. Conclusion

Linear guides are increasingly put to use in applications that require guides with greater degrees of sophistication while meeting a diverse range of requirements. NSK is addressing these needs with newly developed technologies and new linear guides that offer higher performance and higher functionality. A few of these products and technologies have been introduced in this article.

NSK will continue to develop technologies and propose products that will respond rapidly to a diverse range of demands and applications.

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Masaru Hattori

Technological Trends of Ball Bearings for Household Electrical Appliances

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ABSTRACT

Ball bearings used in household electrical appliances have achieved increasingly higher functionality over the years in response to demand for higher performance of such appliances. This article discusses the related trends and technologies of the ball bearings used in these appliances.

1. Introduction

Ball bearings have been used in home appliances in Japan since the 1950s. At present, more than a hundred bearings are used in home appliances owned by a typical Japanese household. Due to versatility and cost, standard bearings are commonly used in these appliances. Occasionally, however, some motors require bearings that offer a higher degree of functionality, such as with the fan motor of an air conditioner. Suction motors that are used in vacuum cleaners also require such specialized bearings. This article will discuss the trends affecting bearings used in these home appliances, and will introduce various related technologies developed by NSK.

2. Fan motor ball bearings

In Japan, a large number of appliances use fan motors including air conditioners, range hoods, air purifiers, and exhaust fans. Air conditioners became widespread in the 1970s, and presently 60 to 70 million units are sold annually. As the use of air conditioners spreads throughout Asia and European regions, further market expansion is expected. Accordingly, the bearings used in fan motors for these air conditioners are increasingly expected to provide higher degrees of performance and reliability. Here, each performance factor is discussed in greater detail.

2.1 Quiet-running performance

Any undesirable sound that is generated from a motor in a home appliance is simply regarded as noise. Therefore, almost any home appliance motor must operate as quietly as possible. This requires that the bearings used in motors for these appliances provide high degrees of quiet-running and low-vibration performance. Air conditioners and air purifiers, which might be used in sleeping quarters at night, are particularly susceptible to strict demands for quiet-running performance. The most common sound that is generated from a bearing is called race noise, which is a type of noise that is generated from all rolling bearings. The race noise level is influenced by the accuracy of the raceway, such as the degree of waviness or roughness of the bearing raceways or surfaces of rolling elements. Ever since air conditioners became commonplace for home use, NSK has been making steadfast improvements to the accuracy of these factors in an attempt to enhance the quiet-running performance of bearings and to further lower their vibration levels. As a result, vibration levels of a 608 ball bearing, which is typically used in a fan motor, have significantly dropped[1] over the years, as is shown in Fig.1.

However, as vibration levels decreased and race noise became quieter, other sounds that were not readily audible gradually became conspicuous, and were considered to be harsh noises that need to be addressed. Two examples of such noises are flaw noise and cage noise. Flaw noise is associated with small imperfections that are found on the surfaces of rolling elements or bearing raceways. Cage noise is associated with a vibrating cage. Flaw noise was addressed by eliminating excessive waviness and by addressing any surface imperfections through a manufacturing process that provided a smoother finish on the surfaces of the raceways and the rolling elements. In regards to cage noise, NSK conducted research and development to discover a means of reducing cage noise. This R&D revealed that controlling cage movement would be effective in reducing cage noise. A new cage design was thus put into practical use that effectively restrained cage movement for improved quiet-running performance.

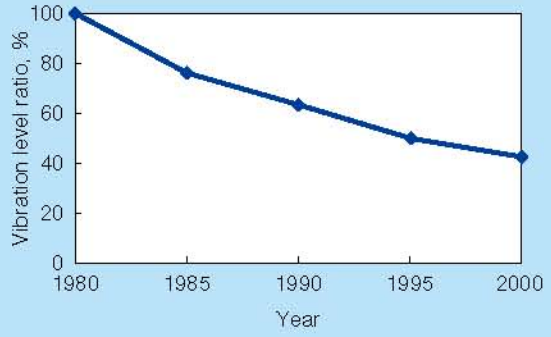


Fig. 1 Gradual drop in vibration levels of 608 ball bearings for fan motors[1]

2.2 Extended service life

(1) Grease

Bearings used in a typical fan motor are lubricated with standard lithium-soap grease such as NS7 or NSC grease. However, as the service life requirements of products are further extended with each passing year, there arose cases where bearings packed with standard grease were unable to satisfy the grease life (seizure life) requirements. To enhance seizure life, urea grease has proven to be effective. Among the various types of urea-based grease products, urea grease containing a base oil with high kinematic viscosity has proven to be even more effective. However, urea grease containing base oil with a high kinematic viscosity risks increasing bearing fiction loss. If bearing friction loss increases to an unacceptable level, however, urea grease containing a base oil with low kinematic viscosity (for example EA3 grease) can be used. The friction loss of EA3 grease is equivalent to that of NS7 grease, but features a grease life that is longer by twofold. Fig. 2 illustrates the seizure life test results of NS7 and EA3 grease products.

(2) Cage

Bearings used in fan motors typically have a bore diameter ranging from 8 mm to 15 mm. Of these, plastic cages are used in about 90 % or more of those bearings with a bore diameter of less than 10 mm (608 bearings). On the contrary, pressed steel cages are more common for bearings with a bore diameter of 10 mm or more (6200, 6201, 6202, etc.), which is due to differences in operating conditions or service life requirements. In comparison to pressed steel cages, plastic cages feature self-lubricating properties, generate fewer worn particles, and offer a greater degree of elasticity, which helps the cage to accommodate some misalignment or moment loads. Although, plastic cages are limited to use in conditions operating in a lower temperature range, bearing life test results thus far confirm that plastic cages are more effective in extending bearing service life by more than twofold than that of a bearing using a pressed steel cage. Whereas the operating conditions of a fan motor bearing are basically at lower temperatures, plastic cages for bearings with a bore diameter of 10 mm or more are considered to be most effective for such an application[2]. Fig. 3 illustrates a comparison of durability between a bearing with a plastic cage and a bearing with a pressed steel cage. An additional advantage of using plastic cages is that they afford a considerable degree of freedom in that they can be designed and molded into an optimum configuration to accommodate a given application. Thus said, NSK aims to achieve development of highly functional bearings with enhanced bearing life by promoting the standardization of plastic cages for bearings with a bore diameter of 10 mm or more for fan motors.

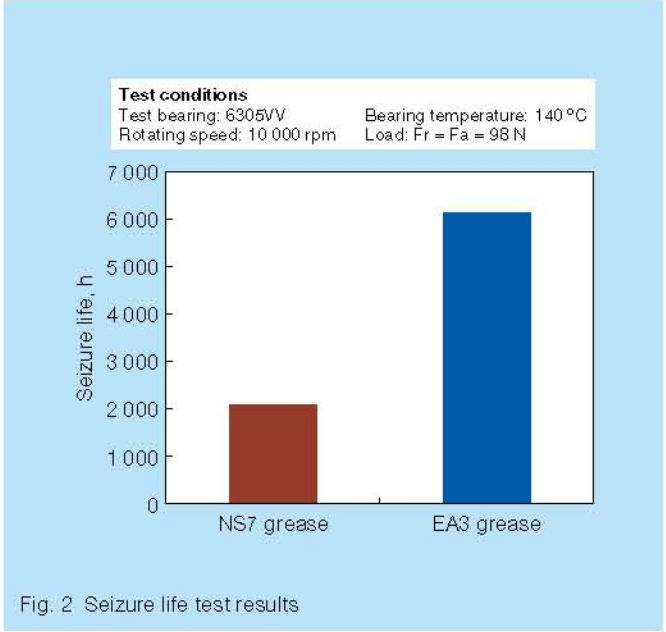


Fig. 2 Seizure life test results

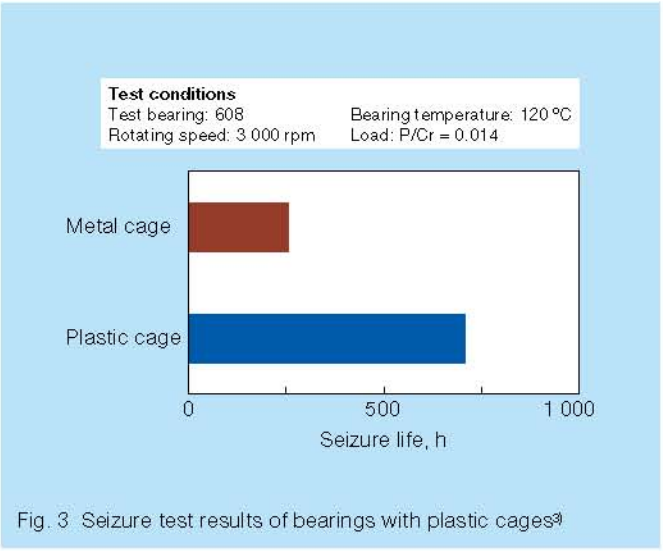


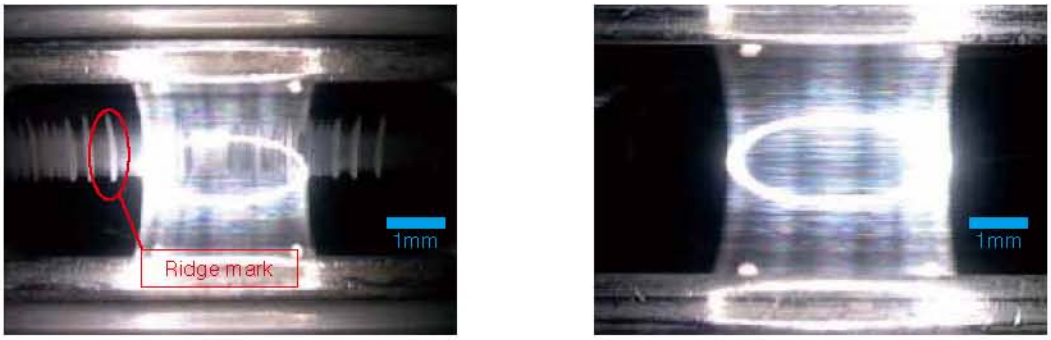
Fig. 3 Seizure test results of bearings with plastic cages[3]

2.3 Prevent electrical corrosion

Air conditioners sold in Japan and Western countries these days tend to use inverters to control the fan motors. Inverters are also used to control fan filter units (FFU) in cleanroom applications. With higher frequency of AC current, electrolytic corrosion (sometimes referred to as high-frequency electrical corrosion at NSK), began to affect the bearings used in inverters. Until 2004, this problem rarely occurred. In recent years, however, such corrosion became so widespread that it had to be addressed. One measure that motor manufacturers have taken is to reduce the amount of shaft voltage. However, there are limits to how much shaft voltage and leakage current of the motor can be suppressed. NSK addressed this issue by considering measures that focus on the bearing itself.

Although the mechanism of electrolytic corrosion is not been clarified yet, the following facts regarding this type of corrosion are known:

- Becomes more pronounced when carrier frequency exceeds 10 kHz.
- Occurs under continuous rotation of the bearing, which results in excessive vibration and loud noise.



(a) Inner ring of bearing with steel balls (b) Inner ring of bearing with ceramic balls

Photo 1 Reproduced test results of electrical corrosion using 6201 ball bearings

- Wave-like wear marks, which are also known as corrugation, may occur on the inner ring or outer ring raceway surface.
- Does not necessarily occur in all of the same models of a given application.

The only solution that has proven effective as a measure against electrolytic corrosion has been to provide some type of insulation between the outer and inner rings. To this end, ceramic balls are often used as the rolling elements. NSK reproduced the damage of electrolytic corrosion by forcibly applying current to a bearing. As a result, no damage occurred in the bearing with ceramic balls. The comparative observation results of a bearing with ceramic balls and a bearing with steel balls are shown in Photo 1. However, since the raw material of a ceramic ball is more expensive than that of a steel ball, actual adoption in the field of bearings using ceramic balls as the rolling elements remains relatively small.

In the process of conducting tests, we found that increases in bearing vibrations resulting from electrolytic corrosion varied according to certain bearing specifications. Fig. 4 shows increased vibration levels for differing bearing specifications. Test results revealed an increase in bearing vibration levels with changes in the oil film parameter (Λ), which was relevant to each bearing specification. We learned that the smaller the oil film parameter, the smaller the increase of vibration. The bearing specification maintaining a low oil film parameter is not a perfect solution because the increase of vibration is not zero, but is considered to be effective as a means of reducing the amount of increase in vibration when a bearing is damaged.

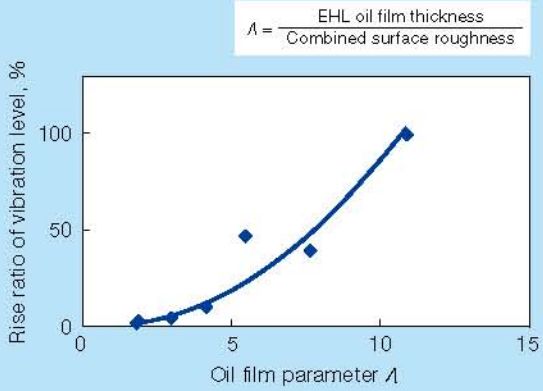


Fig. 4 Relationship between oil film parameter Λ and rise of bearing vibration caused by electrical corrosion

2.4 False brinelling resistance

False brinelling is a type of wear that can occur on the raceways of fan motor bearings used in air conditioners. False brinelling may occur during transportation of the fan motor and is subject to road conditions at length of transportation. This type of wear is caused by minute movements at contact points between the rolling elements and the raceways during transportation and is indicative of excessive external vibration when the bearing is not being rotated. An example of false brinelling damage to a 6201 ball bearing is shown in Photo 2.

Packing the bearing with grease that contains base oil with a high kinematic viscosity is an effective measure against false brinelling. However, grease that contains base oil with a higher kinematic viscosity risks a higher degree of friction loss in the bearing, and causes problems under low-temperature operating conditions. Therefore, both advantages and disadvantages must be weighed carefully when selecting a grease product.

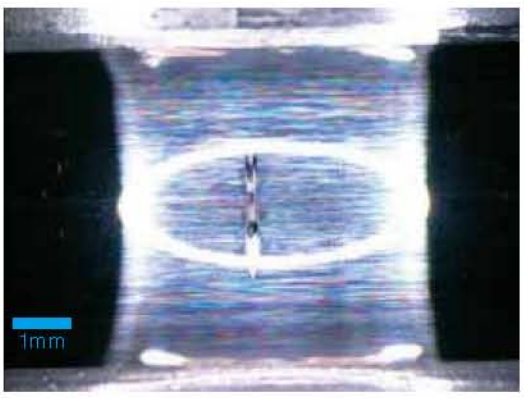


Photo 2 Example of false brinelling on a 6201 ball bearing

NSK addressed the problem of false brinelling by optimizing bearing internal design, and developed a specific bearing for fan motors used in air conditioners. Fig. 5 shows a comparison of test results for the newly developed bearing and a typically used 608 bearing. In this figure, the effectiveness of an optimum internal design as a measure against false brinelling is illustrated by the difference in increased amounts of bearing vibrations.

In addition, NSK made serious effort to improve false brinelling resistance through the use of grease containing base oil with a low kinematic viscosity. The result was successful development of EA7 grease. EA7 grease used in servomotors has a proven track record for its ability to perform with relatively small frictional torque at low temperatures, and for its effectiveness in preventing false brinelling. Fig. 6 shows a comparison of false brinelling test results for bearings packed with EA7 grease and NS7 grease.

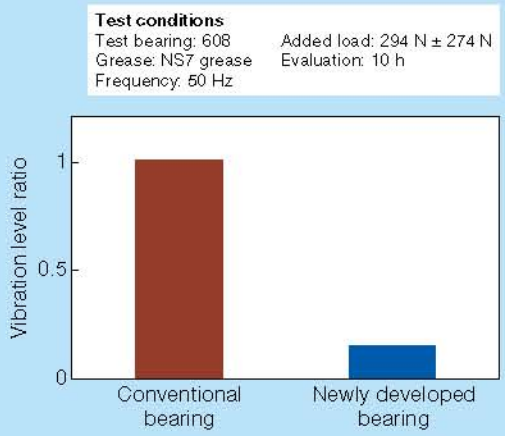


Fig. 5 False brinelling wear test results (1)

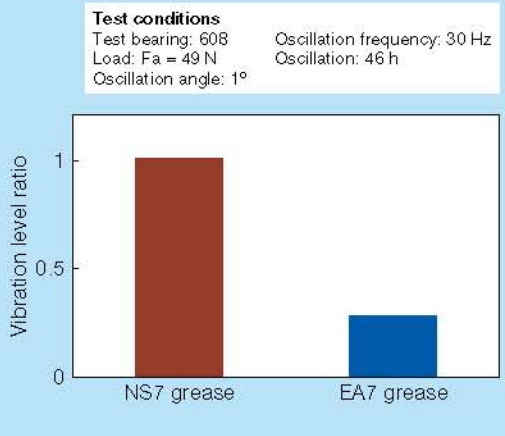


Fig. 6 False brinelling wear test results (2)

3. Ball bearings for vacuum cleaner suction motors

The market size for household vacuum cleaners is almost the same as that for air conditioners. In discussing vacuum cleaners, we need to understand that the concept of suction force strength and the concept of suction efficiency are often combined into a single expression: suction power. The suction power of vacuum cleaners has shown a year-by-year increase in Japan. Additionally, products with higher power ratings are constantly released one after another (suction power is defined as the product of three factors: suction amount, air flow, and JIS coefficient). In addition, suction motor bearings play an important role in improving suction efficiency, which is defined as the ratio of electric power consumption and suction power. Suction efficiency has also improved by efforts to restrict bearing frictional loss and by improving the properties of the bearing seal. Restricting frictional loss helps to reduce the amount of electric power the motor consumes. Improving seal properties helps to increase the amount of suction. The combination of these efforts results in increased suction power.

Highly durable bearings with high-speed capability are needed to accommodate the high rotating speed of suction motors, which can be in excess 40 000 rpm, in order to facilitate increased amounts of suction. The bearings are also required to have sufficient resistance against abrasive wear debris that is associated with the use of brush motors. NSK conducted research and developed specific bearings for use in vacuum cleaner suction motors that satisfy these requirements and ensures long motor service life. Here, we discuss the developments that took place in order to provide the required functionality of these bearings.

3.1 Reduce friction loss

Since the suction motor bearings are used at high speeds, any sliding of the rolling elements between the raceways has a considerable impact on frictional loss. The amount of sliding friction is influenced by the bearing's internal specifications. Therefore, it became necessary to pursue a suitable bearing design specification. NSK responded with the development of a bearing that was specifically designed for use in suction motors. This bearing has internal specifications that have been optimized by utilizing bearing analytical technology. Fig. 7 illustrates the amount of measured frictional loss in the newly developed bearing. The newly developed bearing achieved a 50 % reduction in frictional loss at a rotating speed of 44 000 rpm in comparison with a conventional 608 bearing. In addition, since the newly developed bearing is able to restrict excess wear, the amount of heat generation associated with sliding friction was also reduced. These two factors are what give the new bearing its durability advantage.

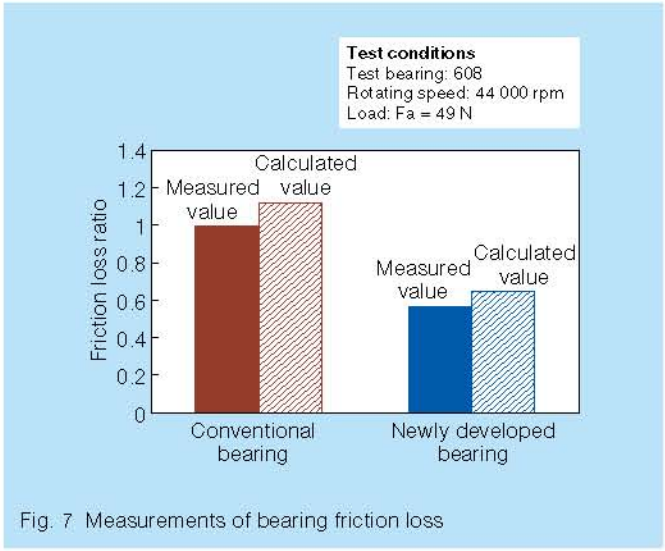


Fig. 7 Measurements of bearing friction loss

3.2 Protect from contaminants and improve sealing capability

Brush motors in vacuum cleaners are naturally subject to wear of the brush as time progresses. As the brush wears, abrasive metallic particles of wear debris are generated. If the bearing suffers a large ingress of wear debris through the clearance between the inner ring and seal, the bearing may suffer a significant degradation of service life. In order to fill the gaps between the inner ring and seal and thus preventing the ingression of wear debris, bearings for vacuum cleaner suction motors are packed with EA3 grease as the de facto standard.

Some vacuum cleaners are designed so that air flowing from the nozzle and finally through the suction fan is allowed to flow through the motor for cooling purposes. If the bearing seal performs insufficiently, some air flowing through the motor may leak from the bearing interior and flow backwards frequently, which can cause loss of suction. To prevent any loss of suction, high-performance seals are required for use in suction motor bearings. In high-power vacuum cleaners, the suction motor bearings use light-contact rubber seals, which offer greater sealing performance over the more common non-contact metal shields (see Fig. 8).

Contact seals are very effective at preventing ingress of foreign matter. However, when a contact seal is used, surface pressure where the seal contacts the bearing increases. Eventually, this increase in pressure will damage the seal and affect sealing performance. If the bearing loses some of its sealing performance, air in the suction motor can leak through the bearing. Furthermore, increased surface pressure results in a greater consumption of electricity, which negates any possibility for improving suction efficiency. NSK addressed this issue with the development of a new seal that withstands contact pressure by increasing rigidity of the seal lip in comparison with that of NSK's light-contact DW seal. Fig. 8 illustrates a comparison of a non-contact metal shield, a conventional contact seal, and the newly developed seal. NSK developed this seal while evaluating leakage pressure and electric power consumption under increased contact-pressure conditions. Fig. 9 shows the layout of the test machine used to conduct this evaluation. The evaluation was conducted by feeding compressed air into the bearing to increase pressure in the bearing. The measured amount of pressure used to push the air through the bearing is defined as leakage pressure. At the same time, comparisons were made of the electrical power consumption required to rotate the motor, which helps determine the amount of bearing frictional torque. The evaluation results for a 608 bearing that was rotated at 45 000 rpm are shown in Fig. 10.

4. Ball bearings for washing machines

Homemakers began using washing machines in Japan in the 1950s. Initially, top-loading, twin-tub washers with impellers were most common in Japan. This type of washer has an impeller mounted at the bottom of the tub and is rotated by a motor and belt drive that generates water action and moves the items in the water to remove

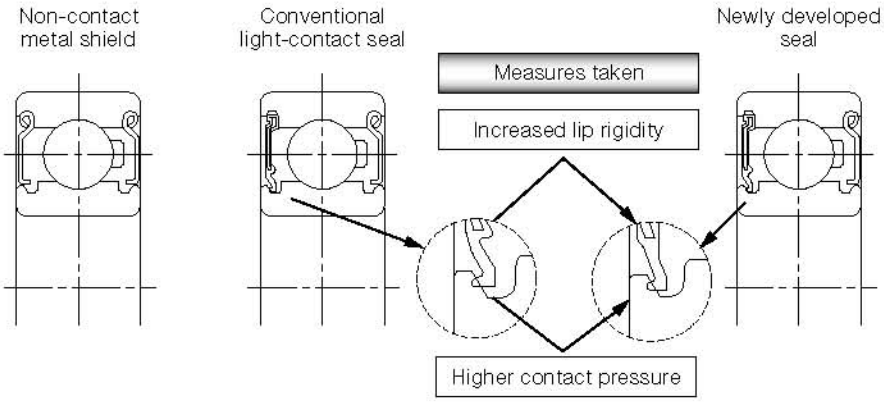


Fig. 8 Comparison of conventional seals and newly developed seal for improved prevention of air leakage

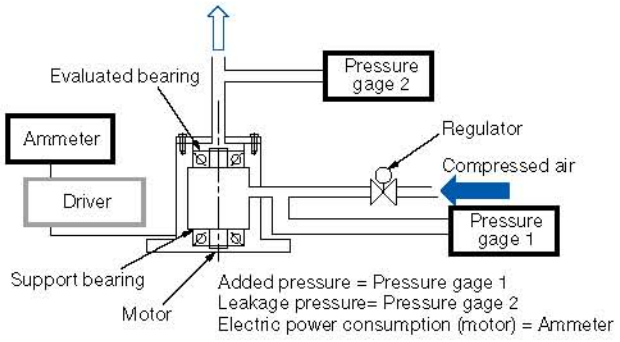


Fig. 9 Layout of pressure test equipment

dirt. In a twin-tub washer, one tub is used for washing and the other tub is for rinsing and spinning. These days, fully automatic, single-tub, top-loading washers have become more commonplace. In response to growing demand for quieter running performance and higher efficiency in terms of saving water and energy, front-loading washing machines, which have either a horizontal or tilted drum (tumbler) that spins on its horizontal axis, are enjoying strong popularity.

Front-loading washers sold in Japan typically use direct-drive tumblers, whereas such washers in Europe use belt-drive tumblers. Each type of drive requires bearings that offer different functionality. Belt drives require high-speed, quiet-running bearings due to increased levels of torque and the use of a high-speed motor. Direct drives require bearings with a thin cross-section profile.

In addition to standard front-loading washing machines, washer/dryer combos that also dry the laundry, and deodorize or remove odors, are becoming increasingly popular. Accordingly, as the trend towards an increased number of motors per washing machine increases, and the number of bearings used in these motors also increases, other appliances including air conditioners and vacuum cleaners, will require bearings capable of providing ever-higher degrees of functionality.

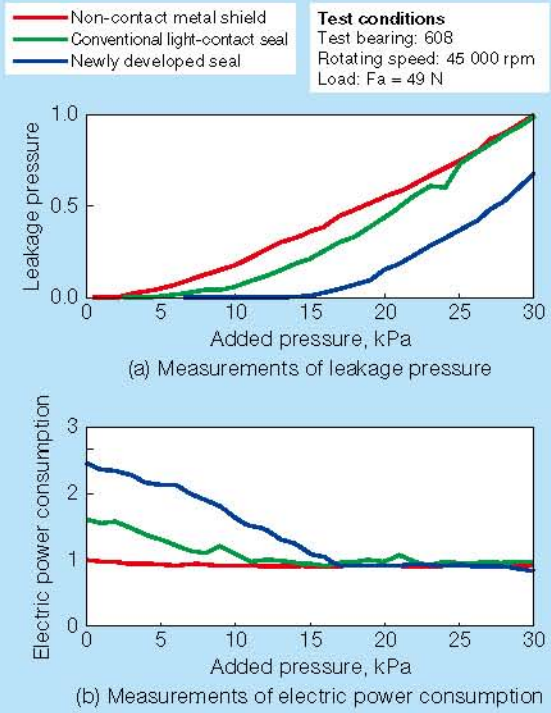


Fig. 10 Measurements of seal performance evaluation tests

5. Conclusion

In this article, we have reported on the related trends and technologies of ball bearings used in a few home appliances such as fan motors, and vacuum cleaners, and washing machines. With each passing year, the bearings used in these applications are expected to meet increasingly stringent requirements. NSK will continue to meet the needs of users by developing products that are environmentally sound through the application of basic technologies that encompass tribology and analytical processing.

This article is a modified version of a similar article that NSK submitted to the Monthly Tribology for publishing.

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Atsuhiro Yamamoto

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Development of a Plastic Cage for High-Performance, Electric Motor Ball Bearings

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ABSTRACT

In this paper, we introduce NSK's newly developed plastic cage. This cage serves as a key component in bearings, which are under growing pressure in recent years to meet the high-performance requirements of electric motors for industrial and home appliances.

1. Introduction

In recent years, high-performance electric motors for industrial and home-use applications require significantly improved ball bearings that offer higher functionality. Ball bearings for home-use applications, such as washing machine motors, and especially fan motors that are used in air conditioners, must provide an even higher degree of quiet-running performance. Furthermore, electric motors for industrial applications require bearings that provide a high degree of resistance against seizure for long-life performance in addition to low-noise performance.

In terms of general versatility and cost performance, standard bearings with balls and pressed steel cages are typically used for such motors. Applications requiring a greater degree of quiet-running performance and longer seizure life may opt for ball bearings with plastic cages instead.

This article reports on a newly developed plastic cage in light of the information presented in the introduction. This newly developed cage facilitates improved lubrication between the rolling elements and cage pocket surfaces, which was made possible by redesigning the cage pockets. Thus, the requirements for quiet-running performance and improved cage strength were achieved without sacrificing the long seizure life and low frictional loss advantages of a plastic cage.

2. Performance requirements and key factors in development of electric motor ball bearings

Table 1 lists various examples of the performance requirements for bearings used in electric motors, which differ for each industrial and home-use application.

2.1 Quiet-running performance

Manufacturers of electric motors that are mounted in home appliances, which include washing machine motors, air conditioner fan motors, and other fan motors for home appliances, have continually strived for the development of motors that operate at ever-lower noise levels.

Although there are various types of noise generated in motor bearings, there are a few basic types of noise. One such noise is referred to as race noise, which is caused by inaccuracies such as waviness or roughness on the surface of the raceway or a rolling element. Flaw noise, which is caused by a small flaw or indentation on the raceway or rolling surface, is another common type of noise. Almost all noise generated in association with the accuracy of a raceway or the surface of a rolling element is static in nature. In addition to static noise, there is contamination noise, which is a type of irregular noise resulting from extremely small pieces of wear debris that have originated from inside the bearing itself or by the ingress of foreign debris that have become caught between the bearing raceway and rolling elements.

However, with improvements that have been made to raceway accuracy, rolling element surface accuracy, and bearing interior cleanliness, race noise and flaw noise have given way to closer scrutiny of a different noise that is referred to as cage noise, which is caused by cage vibrations. In many cases, cage noise is generated irregularly and randomly. When cage noise is generated in an electrical home appliance, especially in a relatively quiet environment, even a small amount of cage noise can be readily recognizable as a source of discordant noise.

Until recently, bearing manufacturers have used pressed steel cages in bearings for home appliance motors as a means of reducing cage noise in response to strict

Table 1 Performance requirements for electric motor ball bearings

	Quiet	Life		Low frictional loss	Cage strength
	(Low noise)	Seizure life	Sound life		
Air conditioner fan motor	○	○	○	○	
Washing machine motor	○	○		○	
Home appliance fan motor	○	○	○	○	
Industrial motor		○		○	
Power tool motor		○		○	○

requirements for quieter running motors. As low-noise requirements have become increasingly strict, bearings using pressed steel cages in some applications have been replaced with bearings using plastic cages. However, it is not possible to completely suppress cage noise even when a plastic cage is used. The primary causes of plastic cage noise are excess motion of the cage or insufficient amounts of lubricant between cage pockets and the rolling elements.

The newly developed plastic cage that is being introduced in this article has a pocket profile that acts as a lubricant reservoir that serves as a measure against cage noise. Thus, cage noise emitted from this new plastic cage has been significantly reduced when compared to cage noise emitted from a pressed steel cage or a conventional plastic cage.

2.2 Cage strength

Vacuum cleaner and power tool motors typically operate at very high rotating speeds. In some cases, the bearings used in such high-speed motors may suffer from misalignment as a result of rise in ambient temperature or faulty assembly. In addition, there are cases where the bearing may become subject to lubricant-starved conditions over time due to certain ambient conditions; and in a worst-case scenario, the cage will become damaged. In industrial motors, however, cage damage rarely occurs. In those rare cases when it does occur, the factors that lead to such damage typically include excessive cage wear due to misalignment or improper lubrication, external vibration, and others. Bearing failure resulting from a weak cage is rare in a ball bearing. In most cases, ball bearing failure results from debris that is generated by wear of the raceways, rolling elements, misaligned cages (due to improper mounting), or excessive loading. This wear debris causes the lubricant to deteriorate until the bearing is operating under conditions of marginal lubricant or excessive vibrations, which eventually causes the bearing to seize and fail prematurely. In this scenario, cage damage is secondary as can be seen in the process flow that is illustrated in Fig. 1.

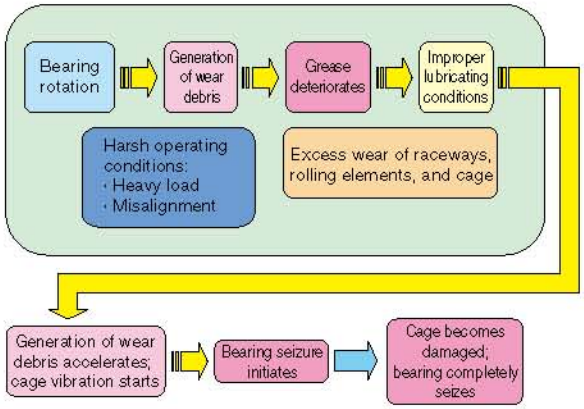

Fig. 1 Process flow of cage damage (example)

From the initial failure mode of bearing seizure to when the cage becomes damaged, wear of the raceways or rolling elements often progresses rapidly, and vibrations and noise from the bearing and the peripheral area where the bearing is mounted become very loud, which is when a bearing abnormality is sometimes noticed. However, the amount of time that transpires from when a conventional pressed steel cage becomes damaged to when the final failure mode of bearing seizure occurs is very short.

In addition to the generation of wear debris between the raceways and rolling elements, additional wear debris that is generated between the cage pockets and the rolling elements deteriorates grease more rapidly, resulting in increased cage vibration. When bearing damage progresses to the final failure mode of bearing seizure, peripheral equipment and connected components typically suffer from severe damage.

Thus, end-users require as much time as possible to address the situation once the initial failure mode of bearing seizure has been recognized. Any efforts by bearing makers to extend that amount of time until the final mode of failure occurs would prove to be of valuable assistance.

Cage strength can be measured by conducting a cage tensile strength test where a load is externally applied to the cage. A comparison of the test results for a pressed steel cage and a plastic cage shows that the pressed steel cage is much stronger. However, a comparison of field-test results for real-world performance of the two cages shows that the plastic cage is far superior. Field test results show that tensile strength alone does not truly reflect the strength of a cage for actual operating conditions.

NSK thus developed a proprietary method for testing cage strength that takes into consideration real-world operating conditions. Using this test method, the operating limits of the cage can be tested more accurately, which in turn have aided in the development of a plastic cage that is stronger and performs better under rotating conditions.

2.3 Frictional loss

The bearings used in electric motors for industrial applications and home appliances need to perform with low frictional loss so that the motors are able to meet requirements for low-energy consumption and improved operating efficiency. Traditionally, good lubricant performance has been at odds with low frictional loss and vice-versa. This conundrum has made it difficult to develop a bearing that operates with both low frictional loss and good lubricating performance.

However, the design of the newly developed plastic cage described in this article is able to achieve a stable flow of lubricant without sacrificing low frictional loss properties on a par with those of a pressed steel cage or a conventional plastic cage. Such an achievement has been made possible because the cage's newly designed cage pocket is able to direct an optimum flow of lubricant into the lubricant reservoir of each cage pocket.

2.4 Life

Service life of a rolling bearing can be divided into three primary properties: seizure life, low-noise durability, and rolling fatigue life. In general, industrial-use motors place a higher priority on long seizure life while home appliance motors place a higher priority on low-noise durability because of quiet-running performance requirements.

The self-lubricating properties of a plastic cage are advantageous in that there is minimal generation of wear debris, which in turn, provides the bearing with a longer seizure life in comparison to that of a bearing with a pressed steel cage. The low generation of wear debris is also advantageous in that it affords the plastic cage with longer low-noise durability, which is a measure of quiet running performance until at which time the noise exceeds levels as determined by home appliance makers. This newly developed plastic cage takes advantage of these superior properties to achieve a longer service life in the most efficient manner possible.

3. Features of the newly developed plastic cage

3.1 Pocket design

Various cage designs of a pressed steel cage, conventional plastic cage, and the developed plastic cage are illustrated in Fig. 2. The structure of a pressed steel cage consists of pocket surfaces that are nearly spherical in shape and are formed by a applying a pressing process to a circular metal ring. The two pressed rings are mounted opposite each other with rivets that are positioned between each pocket. Meantime, the conventional plastic cage and the newly developed plastic cage consist of a synthetic polyamide (nylon) resin material reinforced with glass fiber that is molded into a crown shape. Fig. 3 shows illustrations of the various pocket designs.

The pockets of the pressed steel cage and the conventional plastic cage are designed to accommodate

Fig. 2 Various cage designs

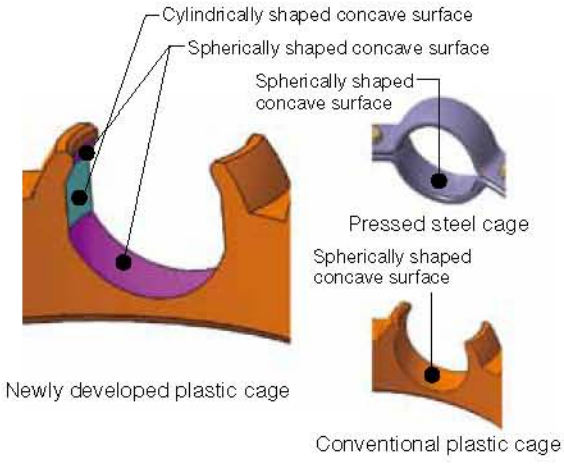

Fig. 3 Various cage pocket designs

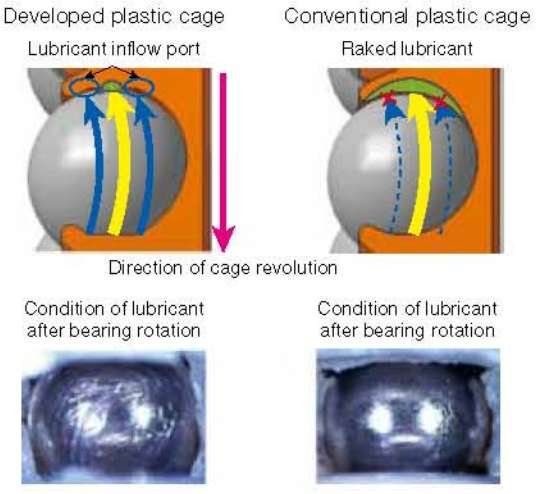

Fig. 4 Condition of lubricant on the ball

a spherical shape that is slightly larger than the rolling elements themselves. On the contrary, the pockets of the newly developed plastic cage are designed to accommodate a spherical shape at both ends in the axial direction while the intermediate portions of the pockets are designed to accommodate a cylindrical shape.

3.2 Lubrication

Fig. 4 shows photos that compare the amount of lubricant remaining on the balls for the different types of cage pockets. The pocket of a conventional plastic cage is designed to accommodate a single spherical surface. Therefore, as the bearing rotates, the edge of the cage pocket removes some of the lubricant from the ball surface resulting in insufficient amounts of lubricant remaining inside the pocket. As the amount of lubricant between the pockets and rolling elements decreases, the coefficient of friction fluctuates resulting in minute cage vibrations.

The pocket of the newly developed plastic cage is designed to accommodate a spherical shape at both ends in the axial direction of the pocket, and the intermediate portions of the pocket are designed to accommodate a cylindrical shape, which is where the rolling element makes direct contact with the cage pocket. This design prevents the removal of lubricant from the running area of the rolling element. The running area makes contact with the inner and outer ring raceways and facilitates the flow of lubricant back into the cage pocket, which facilitates continually good lubricating conditions throughout the bearing. By physically rotating the bearing with this newly designed cage, one can confirm that lubricant adheres to the surface of the rolling elements.

4. Performance of the newly developed plastic cage

4.1 Cage noise

Cage noise test results are shown in Fig. 5. For this test, bearings with a bore diameter of 15 mm, an outside diameter 35 mm, and a width of 11 mm were used. The lubricating grease consisted of a lithium soap thickener and synthetic base oil, which is common for home appliance motors requiring quiet-running performance. Highly accurate inner and outer rings and rolling elements of the same lot were used in order to extract differences in cage performance. Extra steps were taken to ensure cleanliness of the bearing interior. Except for the cages, test conditions of the bearings were identical. A light preload was applied to the bearing and rotating speed was gradually increased until the generation of cage noise could be confirmed. The criterion for cage noise was very low since even a small amount of noise coming from a home-appliance motor would become an issue.

Fig. 5 shows the relation between rotating speed and preload at the time when cage noise was confirmed. Under equivalent preload conditions, cage noise that is generated at higher rotating speeds indicates better quiet-running performance. Test results revealed that the bearing with a conventional plastic cage operated at quieter levels than the bearing with a pressed steel cage, but that the bearing with the newly developed plastic cage operated at even quieter levels than the bearing with the conventional plastic cage.

The bearing with the newly developed cage performed at quieter levels because of the greater amount of lubricant that adhered to the surface of the rolling elements (see Fig. 4). Furthermore, as the rolling elements in the bearing with the newly developed plastic cage retained greater amounts of lubricant on the rolling surfaces, lubricating conditions inside the cage pockets were also considered to be good, which reduced the amount of friction between cage pocket surfaces and rolling elements, thus restricting the generation of cage vibration.

4.2 Cage strength

As described in section 2.2, testing the tensile strength of a cage fails to properly reflect the strength of a cage that is being used under conditions of practical usage in the field. Therefore, cage strength was tested using an NSK proprietary test method that evaluates cage strength

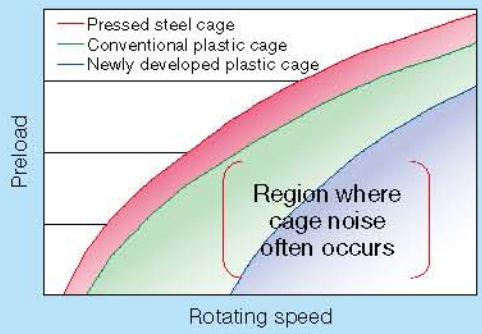

Fig. 5 Cage noise test results

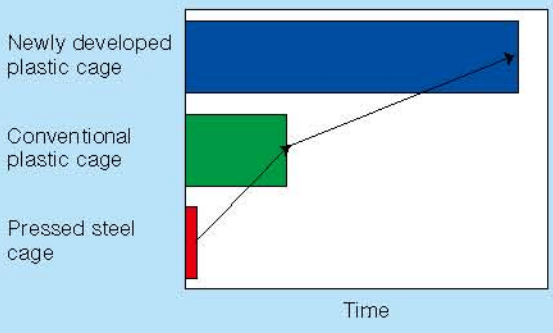

Fig. 6 Cage damage test results

under bearing rotating conditions. The test results shown in Fig. 6 for the three types of cages indicate at what point over time that the cages became damaged.

Bearing specifications used in this test were the same for the bearings used in the cage noise test (bore diameter: 15 mm; outside diameter: 35 mm; width: 11 mm). The bearings were tested under identical testing conditions with the type of cage being the only exception. The conventional plastic cage and the newly developed plastic cage were made of the same material—the only difference being cage pocket design. During testing, conditions to induce bearing seizure were reproduced; and the time from when the bearings seized to when the cages became damaged was measured and compared.

The test results illustrated in Fig. 6 show that the newly developed plastic cage operated approximately 30 times longer than the pressed steel cage, and approximately three times longer than the conventional plastic cage where the only difference was cage pocket design. These test results indicate that the pocket design for the newly developed cage was most likely responsible for reducing contact friction resistance between the rolling elements and the pockets themselves.

4.3 Bearing frictional loss

Results of frictional loss testing are shown in Fig. 7. Bearing specifications for this test were identical to the bearing specifications used in the previously mentioned tests. Although the test results shown in Fig. 7 show a slight difference in frictional loss at the initial stage of testing, it is clear that the newly developed plastic cage showed only low levels of frictional loss, which remained stable early on during testing and was on a par with that of the conventional plastic cage.

The conventional plastic cage, which has a cylindrical section in radial direction, was unable to achieve a low level of frictional loss at an early stage. In order to achieve low frictional loss that remains stable at an early stage of testing, it is necessary to either restrict the amount of cage movement in the radial and axial directions or promote a

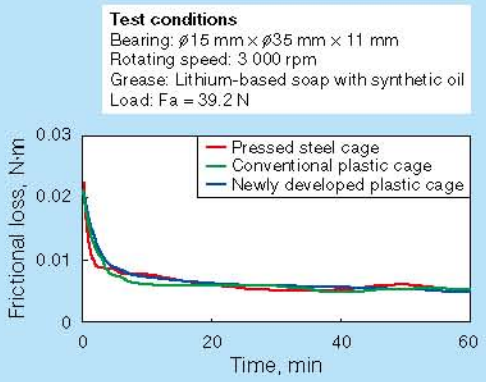

Fig. 7 Frictional loss test results

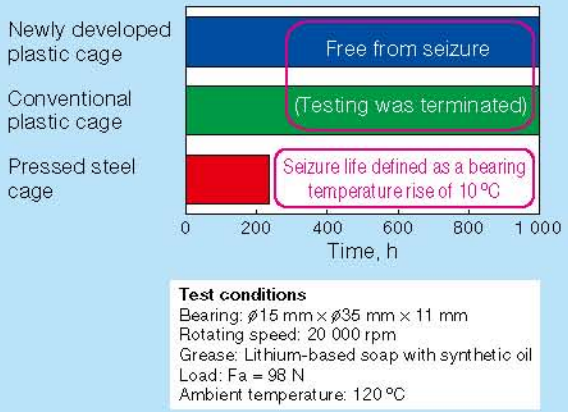

Fig. 9 Seizure life test results (Case 2)

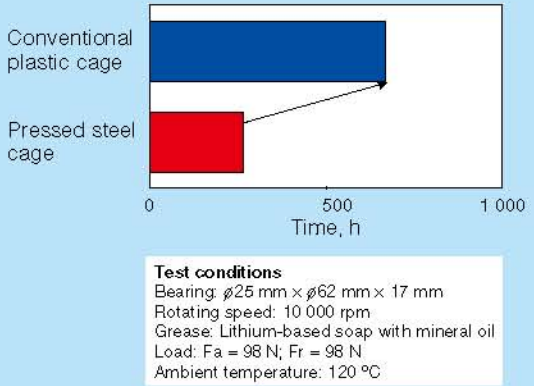

Fig. 8 Seizure life test results (Case 1)

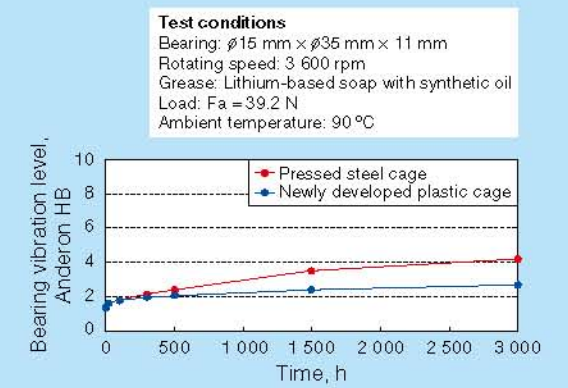

Fig. 10 Sound life test results

greater inflow of lubricant into the cage pocket. The newly developed cage was able to establish and maintain low levels of frictional loss at an early stage of testing because the appropriate amount of lubricant remained on the surfaces of the running areas of the rolling elements that were in contact with inner and outer ring raceways.

4.4 Bearing life—seizure life and sound life

Results of seizure life testing are shown in Fig. 8. In the first case of testing, test results showed that the bearing with a conventional plastic cage had a twofold longer seizure life than that of a bearing with a pressed steel cage. The test results shown in Fig. 9, reflect the second case of seizure life testing where conditions, such as bearing size, grease, rotating speed, and load conditions, were changed. In this test, the bearing with a pressed steel cage quickly reached the end of seizure life while the bearings with a conventional plastic cage and the newly developed plastic cage remained operable after 5 000 hours had elapsed.

Based on these results, it has been verified that the seizure life of the plastic cage is longer than that of the pressed steel cage. Results of sound life testing are shown in Fig. 10. The results show that the bearing with a plastic cage remained quieter and had better low-noise performance for a longer extent in comparison to the results of the bearing with a pressed steel cage.

5. Conclusion

In this article, we have reported on the design and functions of a newly developed plastic cage for highly functional, motor ball bearings. Electric motors for industrial use and home appliances place severe requirements on the performance of bearings that are used in such highly functional motors. In response to maker needs, NSK has responded with this newly developed plastic cage. We will continue to address future challenges that meet the needs and fulfill the requirements for highly functional bearings of our clients.

Hironori Suzuki

Keiji Yasunaga

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Research of Electrically Conductive Grease for Office Equipment Bearings

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ABSTRACT

Electrically conductive grease is used in rolling bearings for office equipment, such as copiers, printers, etc. The electrical resistance value of bearings packed with electrically conductive grease increases over time. In this article, we discuss factors related to this phenomenon, and the optimum specifications required of electrically conductive grease. Our research shows that the oil film parameter of bearings using electrically conductive grease should be maintained within a certain range. Furthermore, controlling the oil absorption characteristics of carbon black used in the grease is effective for achieving optimum specifications for the electrically conductive grease.

1. Introduction

Conventional plain paper copiers (PPCs) and laser printers have a grounding mechanism mounted to the rollers used in the paper transport assembly and photoreceptor drum assembly. This mechanism ensures greater print image quality control by dispersing electrostatic charge. However, some PPC makers eliminated this grounding mechanism in an effort to reduce manufacturing costs. Thus, they required an alternative means of preventing the build up of static electricity, such as dispersing electrostatic charge through the bearings.

Basically, two types of bearings are used in the paper transport and photoreceptor drum assemblies: normal temperature bearings for the photoreceptor drum assembly, transfer roller, and paper transport assemblies; and high-temperature bearings for the fuser's upper and lower heated rollers. Some of the bearings used in these rollers are packed with electrically conductive grease. However, the electrical resistance value of bearings packed with electrically conductive grease tends to increase with usage over an extended period of time[1), 2)].

As the print image quality control technologies used in PPCs and printers continually become more advanced, there has been a growing need for bearings that facilitate improved electrical conductivity. In addition, fuser units, where temperatures can reach as high as 200 °C, require high-temperature electrically conductive bearings as a measure against poor image quality resulting from electromagnetic waves or to ensure high-resolution output[3), 4)]. In addition to high-temperature durability and electrical conductivity, the bearings must be designed to prevent grease from leaking and contaminating the immediate surroundings. The bearing must also operate with low torque to ensure that the rollers used in the paper transport assembly and photoreceptor drum assembly rotate smoothly.

In this research, we have investigated the mechanism where electrical resistance of the bearing rises with time, and have examined the optimum specification of electrically conductive grease in order to restrict it. At the same time, we have introduced NSK's series of electrically conductive bearings for office equipment[5)], which were developed by applying the results of this research.

2. Properties of electrically conductive grease

2.1 Rise in electrical resistance value over time

The time and means of change in electrical resistance of electrically conductive grease was investigated with the use of bearings packed with electrically conductive grease.

Table 1 lists the composition and representative

Table 1 Test greases for measuring the electrical resistance of bearings

	A1	A2	A3	A4	A5
Thickener	Carbon black	Lithium soap & carbon black	Lithium soap & carbon black	Carbon black	Lithium soap & carbon black
Base oil	Ester oil	Mineral oil	Synthetic hydrocarbon oil	Synthetic hydrocarbon oil	Synthetic hydrocarbon oil
Kinematic viscosity of base oil (40 °C), mm²/s	245	104	30	18	18
Worked penetration (25 °C, 60 W)	240	240	244	250	249
Volume resistivity (25 °C), Ω·m	2.6 × 10	3.8 × 10²	9.5 × 10	3.5×10	8.5 × 10

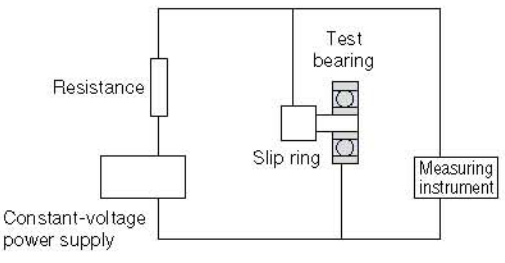

Fig. 1 Diagram of the electrical circuit used for measuring electrical resistance

properties of various electrically conductive greases that were tested. Each grease contained the same type of carbon black, and the viscosity of the base oils used in each grease was adjusted to different values. By adjusting the amount of carbon black that was blended with lithium soap, worked penetrations were set at approximately 250. Resistivity of grease was set to a range from several tens to several hundreds of Ω·m.

Electrical resistance of the bearing (bearing resistance) was calculated after measuring voltage between the inner and outer rings of the rotating bearing using the circuit shown in Fig. 1. The maximum voltage reading was used to define the maximum value of resistance. By adding a resistor to the circuit, we minimized the flow of electricity through the bearing interior and were careful not to generate electrical (electrolytic) corrosion.

Table 2 lists the test conditions and resistance of the tested bearings, which were on a par with the operating conditions and resistance of bearings used in office equipment, and Figs. 2 and 3 show the test results.

Fig. 2 illustrates the relationship between bearing resistance and the kinematic viscosity of the test grease base oil for the first set of test conditions listed in Table 2. When testing the electrical resistance of the bearing, all of the tested greases showed good electrical conductivity right after initial bearing rotation.

However, bearing resistance increased after 50 and 100 hours of rotation as kinematic viscosity of the base oil increased. Fig. 3 illustrates the results of tests conducted for various lengths of time ranging from 100 to 1 000 hours. Bearing resistance rose to 80 kΩ and higher after 100 hours of rotation under the third set of test conditions, which included significantly higher surface pressures. We then investigated the factors that caused this rise in electrical resistance in the bearing.

Table 2 Test conditions of the electrical resistance of bearings

		Condition 1	Condition 2	Condition 3
Test bearing		Shielded-type ball bearing		
Bearing dimensions, mm	Bore diameter	30	8	4
	Outside diameter	42	19	7
	Width	7	6	2.5
Test temperature		Room temperature	Room temperature	Room temperature
Radial load, N		4.9	19.6	8.8
Maximum contact surface pressure, GPa		0.69	1.34	2.55
Rotating speed, rpm		70	100	150
Prelubricated grease amount		25 % of internal space	30 % of internal space	30 % of internal space

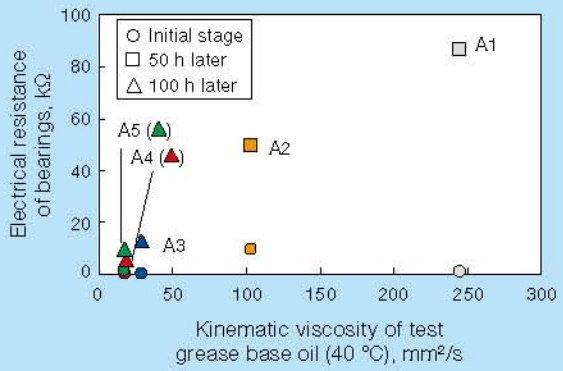

Fig. 2 Relationship between the electrical resistance of bearings and the kinematic viscosity of test grease base oil

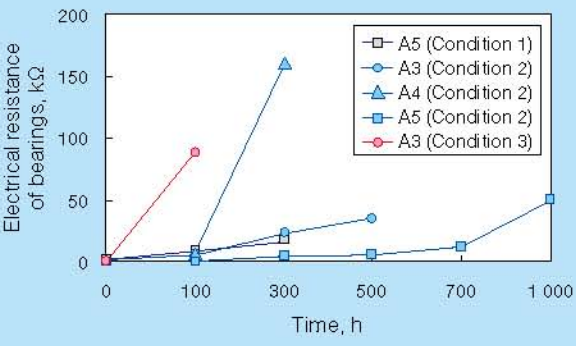

Fig. 3 Increase of the electrical resistance of bearings

2.2 Mechanism of increased bearing electrical resistance

Fig. 4 shows SEM micrographs of the inner ring raceway after testing. Under the first set of low-pressure test conditions, the inner ring raceway surface remained mostly intact and showed only slight wear. Under the second set of test conditions, small amounts of wear and indentations were observed with a greater degree of wear. Under the third set of higher surface-pressure test conditions, the raceway surface was roughest and showed a much greater degree of severe wear. Under high surface-pressure test conditions, the metal-to-metal contact further worsened the surface roughness thus promoting formation of a thick oxide film that increased the electrical resistance of the bearing.

When testing was conducted with A4 grease, raceway surface roughness was much more severe than testing where A5 grease was used. The maximum value for electrical resistance of the A4 grease increased abruptly, as can be seen in Fig. 3. Long-term durability seems to be enhanced by components, such as a soap group, that are effective against boundary lubrication.

In the meantime, electrical resistance of the bearing packed with grease containing a base oil with high kinematic viscosity showed a sharp increase due to cyclic shearing that destroyed the chain structure formed by carbon black. Whereas electrical flow was interrupted, resistance further increased due to the formation of a thick oil film.

Based on the phenomena described above, research was then conducted to determine the optimum condition where bearing resistance could best be controlled. Fig. 5 shows the results of tests that were conducted on bearings for various lengths of time ranging from 50 hours to 100 hours. The figure also illustrates the relationship between the lambda ratio, i.e., the ratio of elastohydrodynamic

lubrication (EHL) oil film thickness to the composite surface roughness, which was calculated using the kinematic viscosity of base oil and the electrical resistance value of the bearings.

Test results show that resistance values were lower for lambda ratios ranging from 0.6 to 3. When the lambda ratio exceeded 3, the oil film was likely too thick. When the lambda ratio was less than 0.6, an oxide film was generated and bearing resistance began to rise. Fig. 6 illustrates this mechanism of increased bearing electrical resistance.

3. Optimum specifications of electrically conductive bearing grease

3.1 Electrically conductive bearing grease for high-temperature applications

In high-temperature applications, such as the heated rollers of the fuser, temperatures can exceed 200 °C during operation. Under such operating conditions, the lambda ratio becomes small, and it becomes difficult to ensure an optimum film formation of the base oil. Under such conditions, oil easily separates from the grease, which demands that measures be taken to reinforce the oil film on the rolling contact surface and restrict oil separation.

Here, the optimum specifications for electrically conductive grease were investigated. Oil film formation on the rolling contact surface was reinforced by an increase in weight of carbon black consisting of different types of electrically conductive carbon black.

Table 3 lists the properties of the differing types of carbon black, including average particle diameter, amount of surface area, and the amount of dibutyl phthalate (DBP) that has been absorbed (and used as an indicator of oil absorption). Perfluoropolyether oil, which is resistant to heat up to 200 °C, was used as the base oil. Combined with the three types of conductive carbon black, grease penetration was adjusted to a range of 220 to 260.

Table 4 lists the composition and properties of test greases and Fig. 7 illustrates the changes in bearing resistance for each grease at 200 °C. The bearing that was packed with grease sample B1, which contained a polytetrafluoroethylene thickener and showed a high degree of resistance from the initial stage of testing, showed very poor conductivity. Polytetrafluoroethylene acts as a highly effective insulator that prevented current flow between carbon black structures on the contact surface.

Grease containing carbon black showed little electrical resistivity (specific resistance) at the initial stage of testing, but bearing resistance was shown to rise if the bearing was packed with grease containing small amounts of carbon black. As a result of this test, tested grease samples with ratios (mass percentage) of electrically conductive carbon black was 6 % or more, continued to show low electrical resistance after 300 hours had passed, and were still in good condition.

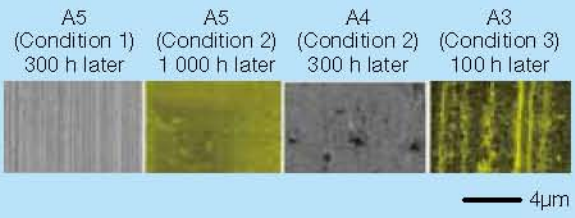

Fig. 4 SEM micrographs of the inner ring raceway after testing

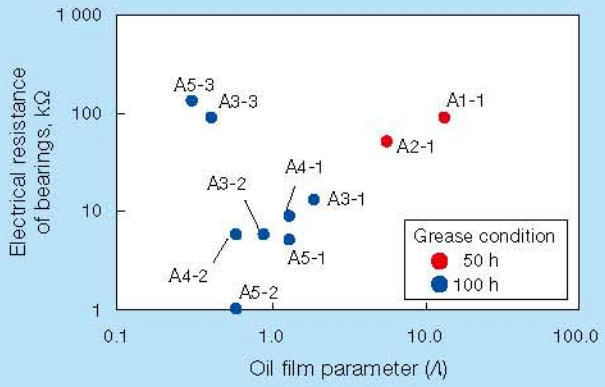

Fig. 5 Relationship between the electrical resistance of bearings and oil film parameter

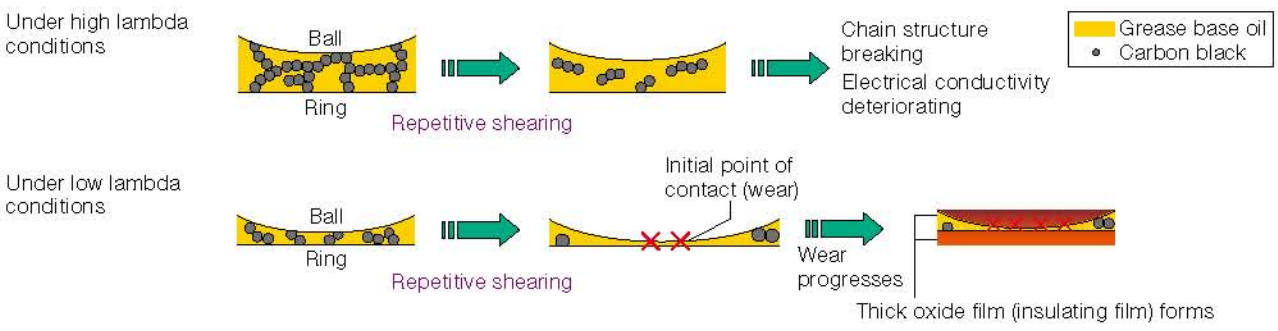

Fig. 6 Mechanism of electrical resistance increasing in the bearings

Table 3 Properties of electrically conductive carbon black

	Average primary diameter, nm	Surface area per 1 g, m²	Average primary diameter, nm
Electrically conductive carbon black, 1	30	800	360
Electrically conductive carbon black, 2	48	39	140
Electrically conductive carbon black, 3	66	27	68

DBP: Dibutyl phthalate

Table 4 Composition and properties of test greases

		B1	B2	B3	B4
Thickener (mass percentage) %	Polytetrafluoroethylene	13	–	–	–
	Conductive carbon black 1	2.5	2.5	1.6	1.5
	Conductive carbon black 2	–	–	4.4	–
	Conductive carbon black 3	–	–	–	13
	Total	15.5	2.5	6	14.5
Base oil		Perfluoro polyether oil			
Worked penetration (25 °C, 60 W)		230	257	243	220
Volume resistivity (25 °C), Ω·m		5.6×10^{-2}	9.3×10	2.8×10	1.9×10
Oil separation (200 °C, 24 h), %		4.4	11	7.1	5.5

3.2 Bearing torque

Samples of grease that comprised of only electrically conductive carbon black were used as the thickener where amounts of carbon black differed for each sample. Using bearings packed with the sample greases, the relationship between the amount of carbon black and bearing torque was investigated.

The results shown in Fig. 8 reveal that increased amounts of carbon black in grease corresponded to increased levels of torque in the bearing, with significantly higher initial torque when the ratio of carbon black was at 20 % or higher. Although the bearings showed similar increases in rotational torque at the initial stage, albeit more gradual, the amount of carbon black in grease was significantly less influential on rotational torque.

3.3 Oil separation properties

After testing was completed, as described in section 3.1, no grease leakage was observed. However, the leakage of oil due to the separation of base oil from the grease was implied. Fig. 9 illustrates the relationship between dibutyl phthalate (DBP) absorption of carbon black with differing absorption properties and the amount of carbon black in grease that had been modified to a penetration of 250.

Differences in oil absorption of carbon black were small regardless of differences in the amount of carbon black in grease. Therefore, it is understood that grease penetration is affected by the oil absorption properties of carbon black. By taking the properties of carbon black, such as surface area (Fig. 10) and oil absorption properties (Fig. 11) into consideration, changes in oil separation after testing under conditions of 200 °C for 100 hours were analyzed. Analysis results are shown in Figs. 10 and 11 respectively. The expression of surface area for carbon black, as indicated in Fig. 10, was per 1 gram of grease. From these results, it can be seen that the surface area of carbon black had little impact on reducing oil separation. Rather, carbon black properties played a greater role in oil absorption rates, as indicated in Fig. 11.

Accordingly, by restricting the oil absorption properties of carbon black, a grease that is comprised of specific amounts of carbon black with an appropriate penetration can be developed where oil separation from the grease can be effectively restricted.

3.4 Ground-free office equipment bearings

The properties of the newly developed proprietary ECE and ECH greases for so-called ground-free bearings are shown in Table 5, and the mechanism of long-term electrical conductivity is illustrated in Fig. 12.

The optimum combination of electrically conductive carbon black and the blend of proprietary additives give the ECE grease for normal-temperature applications longer electrical conductivity than that of conventional

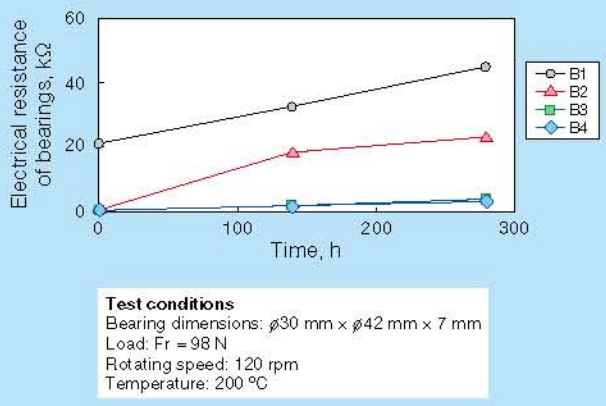

Fig. 7 Increase of electrical resistance in bearings operating under high-temperature conditions

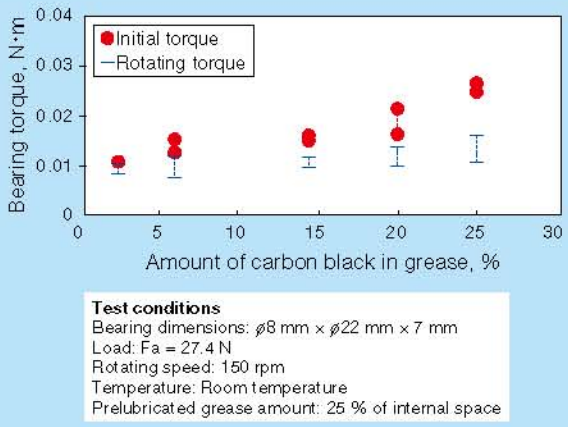

Fig. 8 Relationship between bearing torque and the amount of carbon black in grease

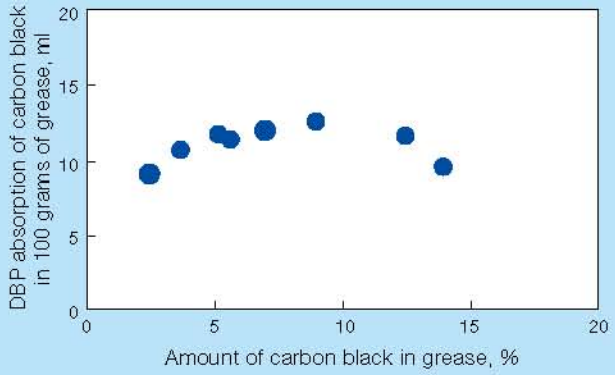

Fig. 9 Relationship between DBP absorption of carbon-black particle and the amount of carbon black in grease with a penetration of 250

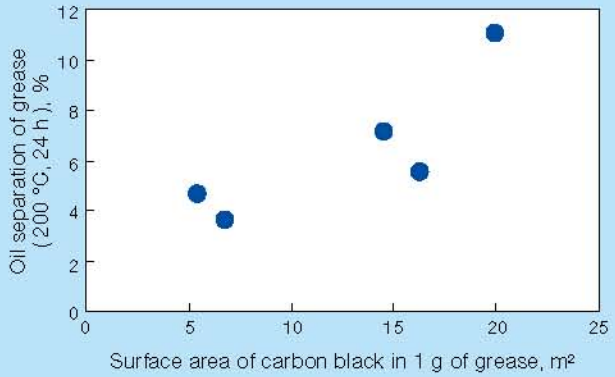

Fig. 10 Relationship between the oil separation of grease and the surface area of carbon black in grease

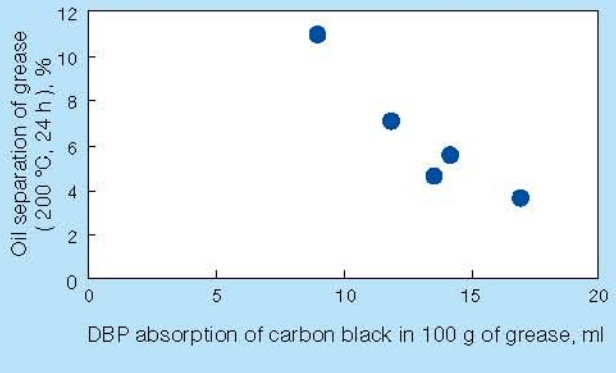

Fig. 11 Relationship between the oil separation of grease and the DBP absorption of carbon black

Table 5 Properties of electrically conductive greases ECE and ECH

	ECE	ECH	Test method
Thickener	Lithium soap and carbon black	Carbon black	
Base oil	Synthetic hydrocarbon oil	Perfluoro polyether oil	
Worked penetration	235	205	JIS K2220
Drop point °C	260 or more	260 or more	JIS K2220
Oil separation %	2.4 (100 °C, 24 h)	6.0 (200 °C, 24 h)	JIS K2220

electrically conductive grease. Bearings packed with ECE grease achieved longer electrical conductivity than that of conventional bearings by eightfold (Fig. 13).

Bearings packed with ECH grease for high-temperature applications extended their electrical conductive performance than that of conventional bearings by fivefold. In addition, bearings packed with ECH grease reduced leakage of base oil by as much as 20 % (Fig. 14), which happens to be a disadvantage of fluorine grease under high-temperature operating conditions.

4. Conclusion

Bearings packed with conventional electrically conductive grease tend to show increased resistance over time. In this article, we investigated the mechanism that increases bearing resistance and clarified the optimum oil film parameter for restricting bearing resistance. In addition, we investigated the optimum specifications for electrically conductive grease. By controlling the oil absorption properties of electrically conductive carbon black, separation of base oil from the grease can be restricted and an optimum amount of carbon black particles can be determined. At the same time, utilizing additives that result in boundary lubrication, it is possible to enhance wear resistance under high surface-pressure conditions.

NSK has developed a bearing series packed with electrically conductive grease specifically for office equipment by taking advantage of the results listed in this article. Electrical conductivity life and reliability of the bearings have been significantly improved. Office equipment makers using these bearings and simplify equipment design, develop more compact components by eliminating mechanical grounding mechanisms, and can enhance the service life of their products.

Portions of this article were originally published in a slightly different form in extended abstracts of Tribology Conference Nos. 2002-10, 2003-5, and 2004-5, and proceedings of the 3rd Asia International Conference on Tribology, which were reprinted by permission of the Japanese Society of Tribologists.

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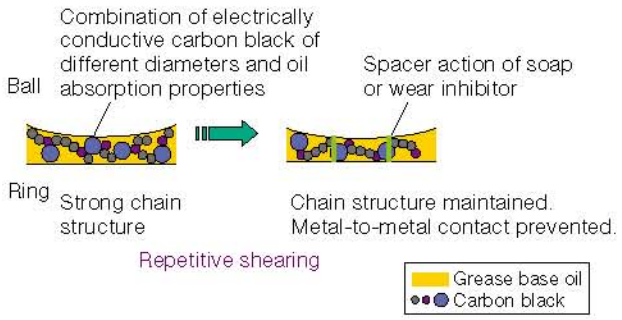

Fig. 12 Mechanism of long-term electrical conductivity of office equipment bearings packed with electrically conductive grease

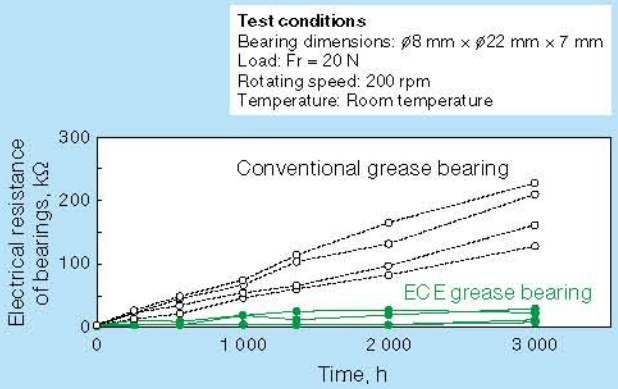

Fig.13 Durability test results of conductivity of office equipment bearings packed with ECE grease (under normal operating temperatures)[6]

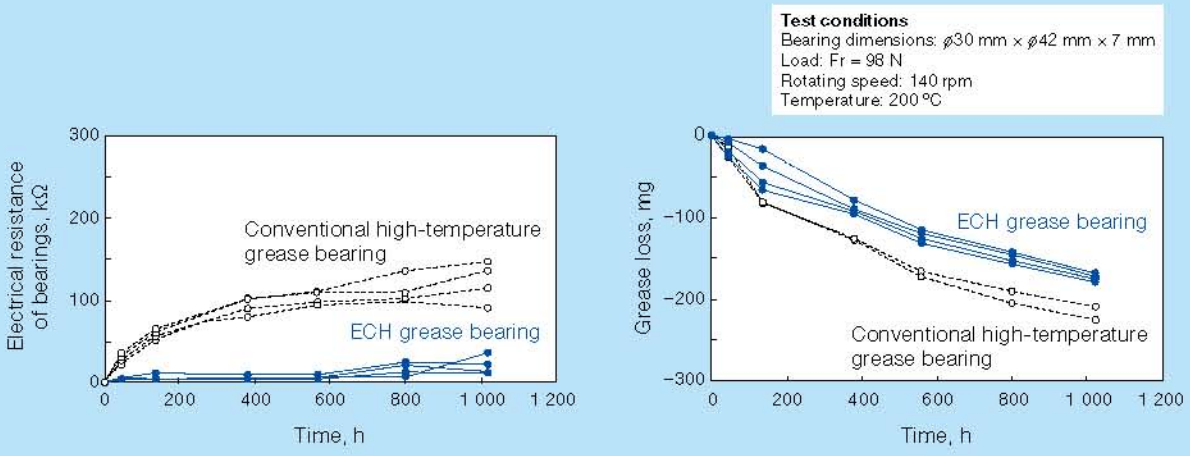

Fig.14 Durability test results of the electrical conductivity of office equipment bearings packed with ECH grease (under high operating temperatures)[5]

2) K. Denpou, M. Naka, "Performance Evaluation of Bearings Prelubricated with Conductive Grease II", Extended abstract of Tribology Conference, Tokyo (2003-5) 235-236.
3) H. Nakamura, T. Shoda, "Conductive Bearings for Office Equipment", NSK Technical Journal, 674 (2002) 24-26.
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7) K. Denpou, A Yokouchi, "Research for an Optimum Specification of Electrically Conductive Grease", ASIATRIB 2006 Kanazawa Volume 1 (2006) 234-240.

Katsuaki Denpou

Michita Hokao

Sensor Bearings for Railway Rolling Stock Axles

NSK has a long history of working hard to improve the performance and to enhance the reliability of axle box bearings for railway rolling stock. In order to further advance the reliability of these bearings, NSK has developed an axle box sensor bearing for railway rolling stock that is capable of monitoring the operating conditions of the bearing. This article introduces the latest developments regarding this bearing.

1. Bearing structure

The newly developed sensor bearing includes an integrated multi-sensor in a compact size that is capable of detecting temperature, vibration, and rotating speed or any desired combination thereof. The multi-sensor is available as an integrated component of the bearing as a single unit or available as a separate component where the sensor and bearing are separated for easier mounting and dismounting of the bearing (Photo 1 and Fig. 1).

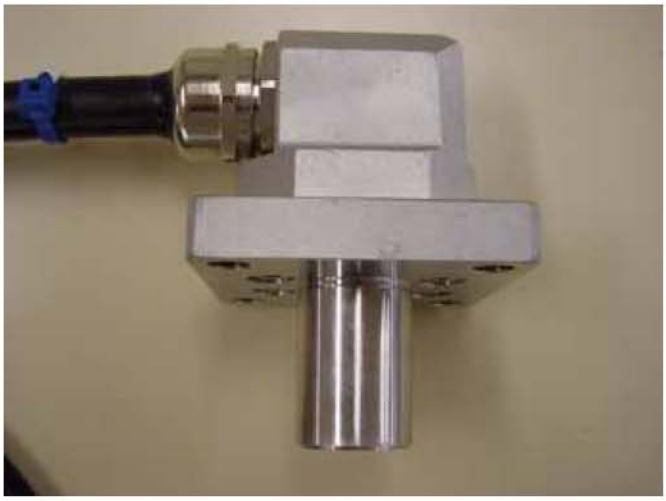


Photo 1 Separated type of multi-sensor unit used in axle bearings for railway rolling stock

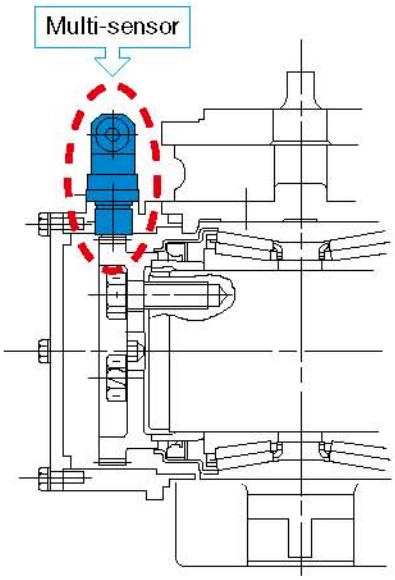


Fig. 1 Separated type of multi-sensor unit used in axle bearings for railway rolling stock

2. Sensor features

In developing the bearing sensor, special considerations were made in regards to impact resistance, vibration durability, and resistance to harsh weather conditions.

(1) Impact resistance

When a rolling stock passes over a railroad switch or joint in the rail, the sensor bearing must endure a strong and sudden impact load. This newly developed bearing has been designed to endure an impact load in excess of 1 000 m/s^2, thus ensuring excellent impact resistance (Fig. 2).

(2) Vibration durability

Whereas axle box bearings are routinely required to operate maintenance-free for approximately 600 000 km, this sensor bearing has been designed to resist damage from constant vibrations for the duration of running periods between maintenance intervals (Fig. 2).

(3) Harsh weather resistance

Since the sensor bearing is exposed to sunlight, wind, rain, and snow, it has been designed to sufficiently resist water splash, and exposure to hot and cold temperatures.

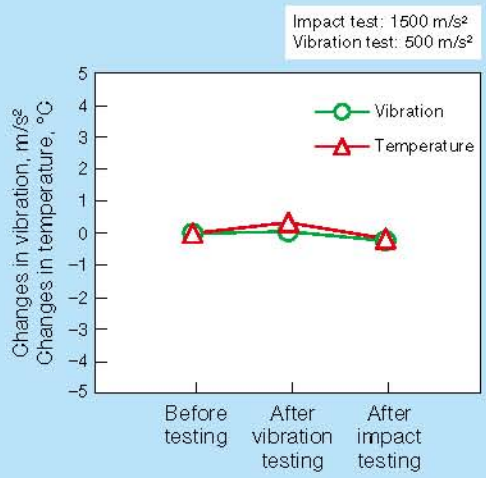


Fig. 2 Mechanical endurance test results of the newly developed sensor

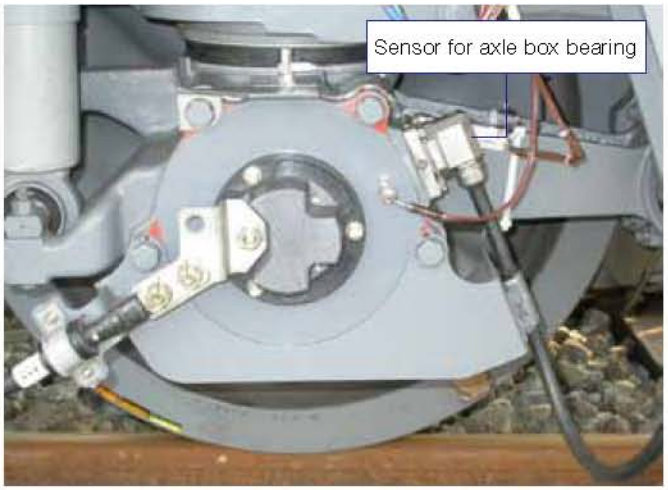


Photo 2 Multi-sensor unit mounted to the housing of an axle bearing for railway rolling stock

3. Sensing functions

(1) Rotating speed

A typical rotating speed sensor is mounted where it measures the rotating speed of the gear that is positioned at the end of the axle. The bearing sensor detects rotating speed through the use of a magnetic detecting element that is mounted on the bearing housing side. This newly developed product maintains the same mounting position for detecting rotating speed as previous products, but has been made available in a more compact design.

(2) Temperature

By sensing the temperature of the bearing and bearing parts in real-time, any temperature rise can be monitored to prevent trouble caused by temperature rise of the bearing or related parts.

(3) Vibration

When a part of the wheel is worn, it may form what is called a wheel flat. Wheel flats damage the rail and cause vibrations that result in an uncomfortable ride. Sensing vibrations can detect wheel flats early on so that action can be taken to ensure a comfortable ride in rail transportation systems.

Additionally this sensor bearing contributes to assured detection of bearing abnormalities by sensing vibration caused by bearings in combination with sensing temperature rise.

4. Real-world application

This sensor bearing has been put to use in the rolling stock of M250 rail cars for hauling containers. Japan Freight Railway Company's so-called Super Rail Cargo container cars, which have a maximum speed of 130 km/h, have been operating for more than five years with NSK's sensor bearings.

5. Summary

NSK's newly developed axle box sensor bearing for railway rolling stock further contributes to improved safety, reliability, and passenger comfort. We expect that this bearing will be widely used in rolling stock in order to meet the needs of rail transportation.

ELCOMP Bearing Series for Screw Compressors in Industrial Applications

Each manufacturer of screw compressors for use in industrial applications uses proprietary lubricating oil to extend the service life of their products and to improve energy efficiency. Recently, manufacturers in Japan and other countries are using alternative or natural refrigerants, such as ammonia gas, for compressors used in refrigerators or air conditioners in response to environmental concerns. These new refrigerants sometimes mix with the oil lubricant that is used in the compressor bearings, which results in a situation where the bearings must continue to provide sufficient durability under lubricant starved conditions and exposure to refrigerants.

NSK has responded to manufacturers needs by developing and commercializing a bearing series that features a long-life resin cage that offers superior oil, chemical, and heat resistance for screw compressors used in industrial applications. This article introduces and reviews the new series of ELCOMP bearings.

1. Product features

1.1 High-capacity design

ELCOMP angular contact ball bearings (Photo 1) offer an approximately 13 % increase in basic dynamic load rating, which was made possible by reviewing bearing internal specifications and optimizing the bearing's internal design. As a result, bearing life has been extended by approximately 50 % in comparison with conventional NSK products.

ELCOMP cylindrical roller bearings (Photo 2) offer an approximately 20 % to 50 % increase in basic dynamic load rating in comparison with NSK's conventional M series, which was made possible by reviewing roller diameter and length and by optimizing the bearing's internal design (Fig. 1).

Photo 1 ELCOMP angular contact ball bearings

Photo 2 ELCOMP cylindrical roller bearings

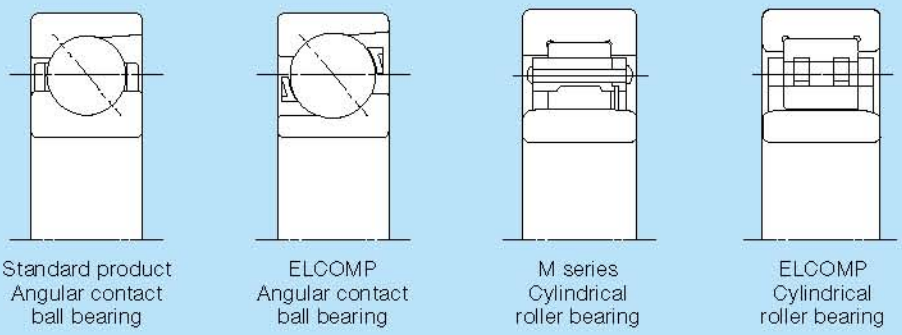


Fig. 1 Cross-section views of angular contact ball bearings and cylindrical roller bearings

Features of cage materials

Material	Nylon 66	Nylon 46	L-PPS
Features	· Standard cage material	· High crystallization offers superior strength at elevated temperatures · Superior heat resistance	· Heat resistance superior to that of nylon 46 · Superior resistance to oil and chemicals · Good dimensional stability
Standard grade	Contains fiberglass	Contains fiberglass	Contains fiberglass
Plastic melting point	262 °C	290 °C	280 °C

Operating temperature guide

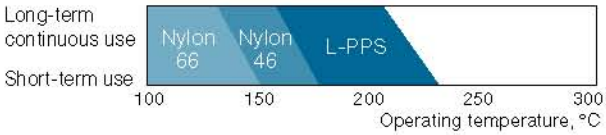


Fig. 2 Features and operating temperatures for plastic cage materials

1.2 Chemically stable resin cage

NSK's patented cage material—linear polyphenylene sulphide (L-PPS) resin—is a high-performance plastic that has been especially developed for conditions where the cage is exposed to refrigerants and refrigerant oil. Detailed features are as follows (Fig. 2).

(1) Oil resistance

Cage is highly resistant to refrigerant or compressor oil (Fig. 3).

(2) Chemical resistance

Cage is highly resistant to ammonia gas (Fig. 4).

(3) Heat resistance

Cage offers superior resistance to heat in comparison to conventional nylon resin cages.

2. Specifications

The ELCOMP series is available in bore diameters ranging from 15 mm to 80 mm for angular contact ball bearings and bore diameters ranging from 20 mm to 100 mm for cylindrical roller bearings (Table 1).

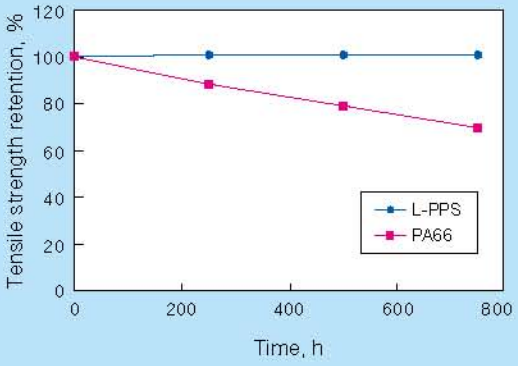


Fig. 3 Resistance to screw compressor oil

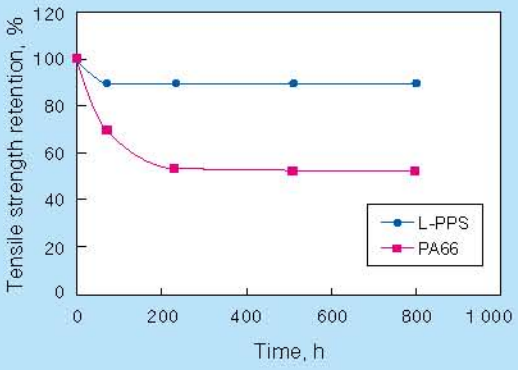


Fig. 4 Resistance to ammonia

Table 1 ELCOMP bearing series lineup

Unit mm

Bearing type	Bearing numbers	Nominal bore diameters
Angular contact ball bearing	72xxB 73xxB	ø15 to ø80
Cylindrical roller bearing	NU (NJ) 2xx NU (NJ) 3xx NU (NJ) 22xx NU (NJ) 23xx	ø20 to ø100

3. Summary

NSK's series of ELCOMP screw compressor bearings for use in industrial applications employs long-life L-PPS resin cages that offer superior resistance to oil, chemicals, and heat. ELCOMP bearings will extend the maintenance intervals for screw compressors while improving energy efficiency.

High-Performance Angular Contact Ball Bearings for Industrial Machinery Pumps

Pumps that are used in various industries throughout the world, including the petrochemical industry, pulp and paper mills, and the food manufacturing industry, are required to be energy efficient and highly reliable. The bearings that are used in these pumps must be compact, manufactured from optimal materials, be lightweight, and must operate with a long service life in order to provide end-users with long-term maintenance-free performance.

This article introduces and reviews NSK's development and commercialization of such high-performance angular contact ball bearings for industrial machinery pumps (Photo 1).

1. Product features

Features of the high-performance angular contact ball bearings for industrial machinery pumps are described below.

(1) Bearing life is improved by 50 % in comparison with conventional NSK products.

Basic dynamic load rating was improved by approximately 13 % by reviewing ball diameter and optimizing the internal design of the rings and cage. As a result, bearing life has been extended by approximately 50 % in comparison with the standard NSK bearing (Fig. 1).

(2) Increased reliability

By improving the shape and guiding method of the copper alloy cage, sufficient space was assured between the rings and cage as well as improved properties of inflow and discharge (Fig. 2). Therefore, the design changes contribute to a more reliable bearing, which increases pump reliability.

(3) Interchangeable for ease of mounting

Interchangeable matching of universal arrangement, single-row angular contact ball bearings is facilitated by the dimensional and running accuracy of these bearings to ISO tolerance class 6. The standard specifications of these bearings contribute to greater work efficiency when mounting bearings to a pump.

Photo 1 High-performance angular contact ball bearings for industrial machinery pumps

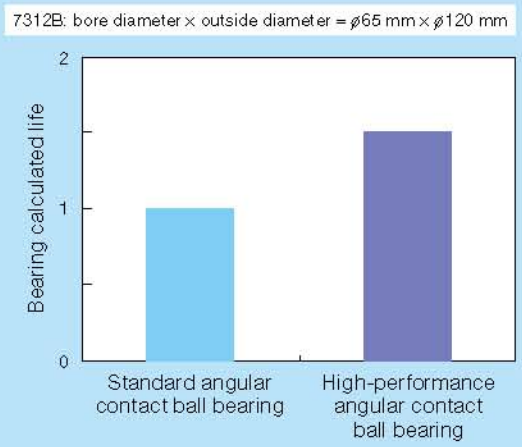


Fig. 1 Comparison of calculated life

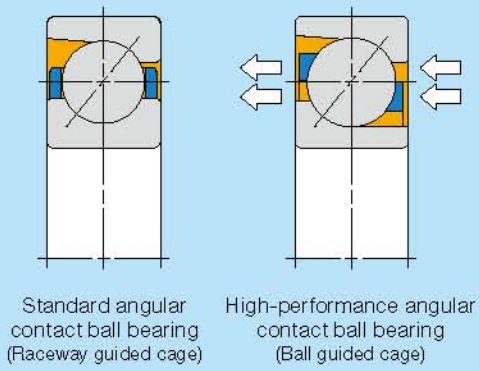


Fig. 2 Cross-section views of angular contact ball bearings showing improved internal design for lubrication flow

2. Specifications

The bore diameter of this series of high-performance angular contact ball bearings for industrial machinery pumps ranges from 15 mm to 80 mm. Boundary dimensions and basic dynamic load ratings are listed in Table 1.

3. Summary

These high-performance angular contact ball bearings for industrial machinery pumps significantly contribute to lower running costs, facilitate downscaling of components, and save energy by extending the maintenance interval. In addition, the copper alloy cage enables use of this bearing in other general industrial machinery.

Table 1 Dimensions and basic load ratings of typical high performance angular contact ball bearings

Unit mm

Bearing numbers	Bore diameter	Outside diameter	Width	Basic load rating (N)
7306BEA	30	72	19	34 500
7309BEA	45	100	25	59 500
7310BEA	50	110	27	74 500
7311BEA	55	120	29	85 000
7312BEA	60	130	31	97 500
7313BEA	65	140	33	108 000
7314BEA	70	150	35	118 000
7315BEA	75	160	37	127 000
7316BEA	80	170	39	138 000

Quiet & Low-Vibration Series of Spherical Roller Bearings for Elevator Applications

Multistory structures, such as office buildings, are increasingly built to greater heights in recent years. Accordingly, elevators for such high-rise buildings are faced with quicker trips and transporting more people. In other words, elevators are required to increase handling capacity at higher speeds. As passenger traffic increases, in-car comfort becomes paramount. Thus, elevators must operate more quietly and more smoothly.

Spherical roller bearings used in elevator hoists must not only continue to ensure superior reliability, but must also reduce bearing rotational noise under increasingly higher operating speeds and heavier-load operating conditions.

NSK has successfully developed and commercialized quiet-running, low-vibration spherical roller bearings that meet the operational requirements of elevator hoists. This article provides a brief overview of this bearing series.

1. Bearing specifications

Photo 1 shows a picture of the newly developed, quiet and low-vibration series of spherical roller bearing specifically designed for elevator applications.

NSK applied years of empirical know-how and applied the acquired technologies towards developing the design specifications of this bearing series in order to reduce bearing noise and vibrations.

(1) Bearing internal clearance

Optimizing internal clearances reduces noise that is generated from the collision of rollers with the inner and outer rings and cage.

- Optimized bearing's internal clearance
- Reduced bearing clearance range to approximately half that of the ISO clearance range

(2) Part accuracy

Smooth rotation was achieved by improving the out-of-roundness and surface roughness of the bearing components.

(a) Rollers

- Out-of-roundness and variation of roller diameter among each manufactured lot was reduced by approximately half that of standard bearings in order to ensure greater roller accuracy.
- Roller surface roughness was improved by approximately three-quarters that of the standard bearing.

(b) Inner and outer rings

- Out-of-roundness was improved by approximately a third that of the standard bearing.
- Raceway surface roughness was improved by approximately two-thirds that of the standard bearing.

Photo 1 Quiet & low-vibration series of spherical roller bearings

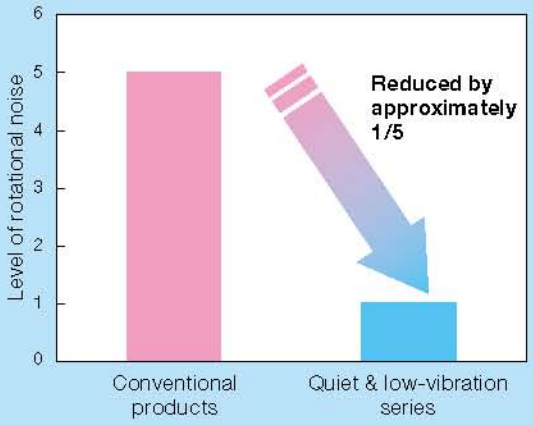


Fig. 1 Noise test results

2. Features

This quiet and low-vibration series of spherical roller bearing employs special design specifications to ensure quiet-running, low-vibration performance of bearings that are used in high-speed, high-capacity elevator hoists. Thus, rotational noise levels of the equipment, in which the bearing is mounted, is reduced by approximately a fifth that of conventional bearings (Fig. 1).

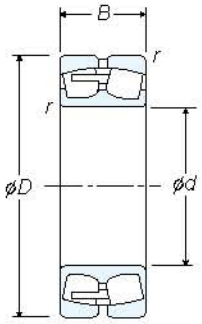
3. Bearing dimensions

NSK's quiet and low-vibration series of spherical roller bearings is available in bearing bore diameters ranging from 100 mm to 400 mm for use in elevator hoist motors. Table 1 lists the boundary dimensions for some typical bearings of this series.

4. Summary

The construction of skyscrapers in China will likely continue in the future, and it is expected that the demand for high-speed elevators will increase. The quiet and low-vibration series of spherical roller bearings developed by NSK offer the indispensable properties required of high-speed elevator hoists, and can contribute to the development of elevators with good ride quality and excellent comfort for use in tall buildings.

Table 1 Specifications of quiet & low-vibration series of spherical roller bearings



Bearing numbers	Boundary dimensions (mm)				Basic load ratings (N)	
	d	D	B	r (minimum)	C_r	C_{0r}
23020CD	100	150	37	1.5	212 000	335 000
24020C	100	150	50	1.5	276 000	470 000
23120C	100	165	52	2	345 000	530 000
24120CA	100	165	65	3	345 000	535 000
22220CA	100	180	46	2.1	330 000	440 000
23220C	100	180	60.3	2.1	420 000	605 000
22320CA	100	215	73	3	600 000	785 000
23030CD	150	225	56	2.1	470 000	815 000
24030C	150	225	75	2.1	590 000	1 090 000
23130C	150	250	80	2.1	725 000	1 180 000
24130C	150	250	100	2.1	890 000	1 530 000
22230CD	150	270	73	3	765 000	1 120 000
23230C	150	270	96	3	975 000	1 560 000
22330CA	150	320	108	4	1 220 000	1 690 000
23940CA	200	280	60	2.1	570 000	1 060 000
23040CA	200	310	82	2.1	940 000	1 700 000
24040C	200	310	109	2.1	1 140 000	2 120 000
23140C	200	340	112	3	1 360 000	2 330 000
24140C	200	340	140	3	1 570 000	2 670 000
22240CA	200	360	98	4	1 300 000	2 010 000
23240C	200	360	128	4	1 660 000	2 750 000
22340CA	200	420	138	5	2 000 000	2 990 000
23952CA	260	360	75	2.1	930 000	1 870 000
23052CA	260	400	104	4	1 430 000	2 580 000
24052CA	260	400	140	4	1 810 000	3 500 000
23152CA	260	440	144	4	2 160 000	3 750 000
24152CA	260	440	180	4	2 560 000	4 700 000
22252CA	260	480	130	5	2 180 000	3 400 000
23252CA	260	480	174	5	2 740 000	4 550 000
22352CA	260	540	165	6	3 100 000	4 600 000
23960CA	300	420	90	3	1 230 000	2 490 000
23060CA	300	460	118	4	1 920 000	3 700 000
24060CA	300	460	160	4	2 310 000	4 600 000
23160CA	300	500	160	5	2 670 000	4 800 000
24160CA	300	500	200	5	3 100 000	5 800 000
22260CA	300	540	140	5	2 610 000	4 250 000
23260CA	300	540	192	5	3 400 000	5 900 000
23972CA	360	480	90	3	1 390 000	3 050 000
23072CA	360	540	134	5	2 390 000	4 700 000
24072CA	360	540	180	5	2 930 000	6 100 000
23172CA	360	600	192	5	3 800 000	7 100 000
24172CA	360	600	243	5	4 200 000	8 000 000
23272CA	360	650	232	6	4 800 000	8 550 000
23980CA	400	540	106	4	1 890 000	4 250 000
23080CA	400	600	148	5	2 970 000	5 900 000
24080CA	400	600	200	5	3 600 000	7 600 000
23180CA	400	650	200	8	4 150 000	7 900 000
24180CA	400	650	250	6	4 950 000	10 100 000
23280CA	400	720	256	6	5 800 000	10 400 000

This table lists some typical bearing numbers of the quiet and low-vibration series for bore diameters ranging from 100 mm to 400 mm.

Creepfree* Bearings for Fan and Pump Motors

An improperly installed fan motor bearing or pump motor bearing can result in a loose fit that can lead to relative movement (creep) between the housing and the outer ring. In recent years, motor manufacturers have increasingly expanded their use of aluminum due to its lighter weight. However, the thermal expansion rate of aluminum housing is higher than that of steel housing, which causes an increased clearance between the outer ring and aluminum housing. With this greater clearance, it is more likely that the bearing will suffer from relative movement or so-called creep. When creep occurs, it will eventually generate an accumulation of wear particles that contaminate the bearing, which can decrease bearing service life. Therefore, there has been growing demand for a bearing that is capable of restricting creep by minimizing any loose fit between the bearing and housing.

NSK has developed a series of anti-creep bearings, or so-called Creepfree bearings, with boundary dimensions on a par with the boundary dimensions of standard bearings for easy retrofitting. This article introduces several features of NSK's series of Creepfree bearings (Photo 1) for fan and pump motors.

1. Structure

This bearing has two O-rings mounted in two grooves

Photo 1 Creepfree bearings

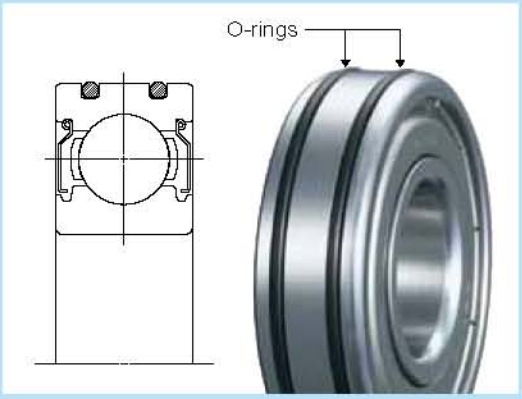


Fig. 1 Structure of Creepfree bearing

Table 1 Series lineup

Bore diameter d (mm)	Bearing outside diameter D (mm)	Bearing width B (mm)	Basic load rating		Recommended fit	Bearing numbers			
			C_r (N)	C_{0r} (N)		Basic bearing numbers	Shield type	Contact seal type	Non-contact seal type
10	26	8	4 550	1 970	G6 or H7	6000	ZZ	DDU	VV
	30	9	5 100	2 390		6200			
	35	11	8 100	3 450		6300			
12	28	8	5 100	2 370		6001	ZZ	DDU	VV
	32	10	6 800	3 050		6201			
	37	12	9 700	4 200		6301			
15	32	9	5 600	2 830		6002	ZZ	DDU	VV
	35	11	7 650	3 750		6202			
	42	13	11 400	5 450		6302			
17	35	10	6 000	3 250		6003	ZZ	DDU	VV
	40	12	9 550	4 800		6203			
	47	14	13 600	6 650		6303			
20	42	12	9 400	5 000		6004	ZZ	DDU	VV
	47	14	12 800	6 600		6204			
	52	15	15 900	7 900		6304			
25	47	12	10 100	5 850		6005	ZZ	DDU	VV
	52	15	14 000	7 850		6205			
	62	17	20 600	11 200		6305			
30	55	13	13 200	8 300		6006	ZZ	DDU	VV
	62	16	19 500	11 300		6206			
	72	19	26 700	15 000		6306			
35	62	14	16 000	10 300		6007	ZZ	DDU	VV
	72	17	25 700	15 300		6207			
	80	21	33 500	19 200		6307			
40	68	15	16 800	11 500		6008	ZZ	DDU	VV
	80	18	29 100	17 900		6208			
	90	23	40 500	24 000		6308			
45	75	16	20 900	15 200		6009	ZZ	DDU	VV
	85	19	31 500	20 400		6209			
	100	25	53 000	32 000		6309			

formed on the outer surface of the bearing's outer diameter. The elasticity and reaction force of the O-rings helps to prevent creep (Fig. 1). Boundary dimensions of this bearing series are the same as those of standard bearings. A total of 30 bearing numbers have been made available for this series (Table 1).

2. Features

(1) Improved creep resistance

We reviewed the dimensions of the O-rings and the O-ring grooves on the outer surface of the outer ring, and optimized the elasticity and reaction force of the O-rings. Bearing creep-resistance was thus improved by more than 20 % that of NSK's conventional bearing (Fig. 2).

(2) Improved creep resistance at high temperatures

By reassessing the composition of the nitrile rubber that is used for the O-ring material, we were able to reduce the O-ring permanent strain in a high temperature environment (120 °C) to one-fifth that of NSK's conventional bearing (Fig. 3). This improvement made it possible to maintain sufficient resistance against creep under high-temperature operating conditions (Fig. 4), which makes it possible to further extend maintenance intervals of motor bearings.

(3) Improved oil resistance

Further, the improved O-ring material features greater resistance to ester-based grease while maintaining the features of nitrile rubber, and enables reductions in the ratio of dimensional changes to one-seventh those caused by oil infiltration (Fig. 5). Improved oil resistance enabled the use of not only mineral oil-based grease, but also enabled the use of ester-based grease for use on the bearing outside surface or housing bore surface when assembling the motors.

3. Applications

This bearing is ideal for fan and pump motors. Additionally, it is suitable for applications such as electric power tools, sewing machines, washing machines, geared motors, servomotors, and general-purpose motors where the fit between the bearing outer ring and housing is loose.

4. Summary

NSK has developed a new series of anti-creep bearings for fan and pump motors and has commercialized them as Creepfree bearings. We will continue to develop products that correspond to the needs of the market in keeping current with changes in application environments.

* The product name "Creepfree" is a marketing term. "Creepfree" should not be construed to mean that creep is nonexistent.

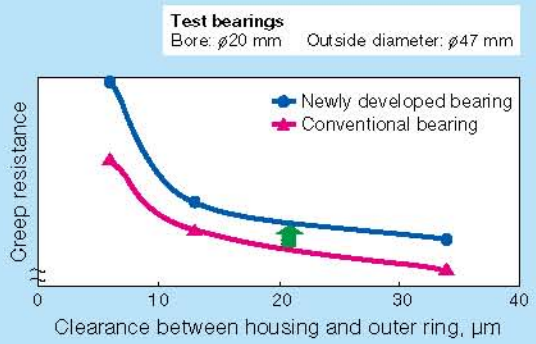


Fig. 2 Creep-resistance test results

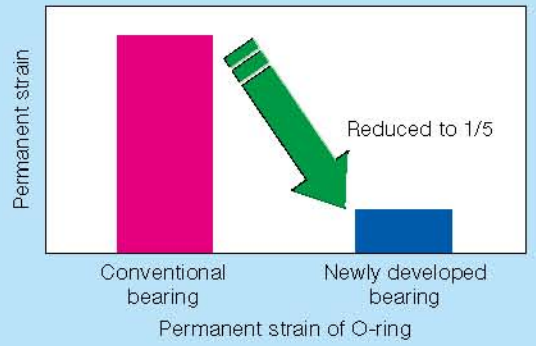


Fig. 3 O-ring tension test results

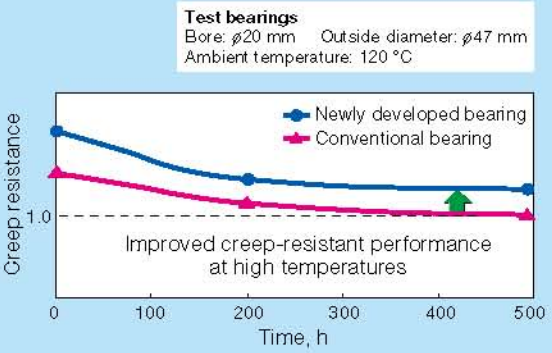


Fig. 4 High temperature durability test results for 120 °C

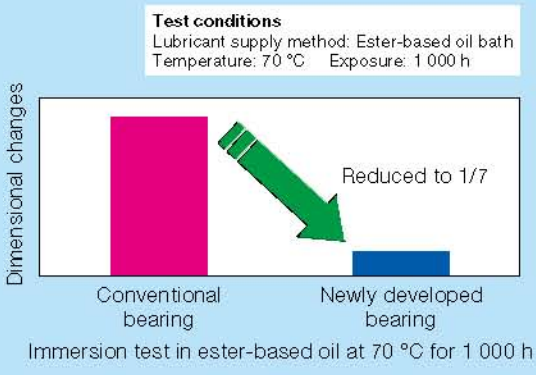


Fig. 5 Ester oil/grease resistance test results

Low-Friction Bearings that Promote Energy Efficiency of Vacuum Cleaner Suction Motors

Suction motors used in current, mainstream household vacuum cleaners operate at high speeds of approximately 45 000 rpm, which accounts for a relatively large amount of energy consumption among household appliances. Therefore, restricting the amount of bearing friction loss that is generated at the time of motor rotation and improving motor efficiency leads to less energy consumption. To this end, NSK has commercialized a new series of low-friction bearings that aim to help save energy by reducing frictional losses while offering longer service life. A picture of this bearing and where it is mounted in a motor can be seen in Photo 1 and Fig. 1.

1. Structure and specifications

This low-friction, energy-efficient bearing has an optimum internal design that reduces friction loss by half without sacrificing the bearing's conventional load rating. Furthermore, the reduced friction helps to restrict the amount of heat that is generated in the bearing, which results in bearing seizure life that is longer by threefold.

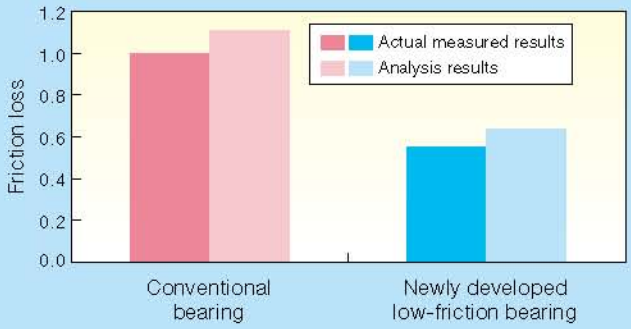
2. Features

(1) Friction loss reduced by half.

By fully applying the latest in analysis technology and by optimizing the internal design of the bearing, sliding

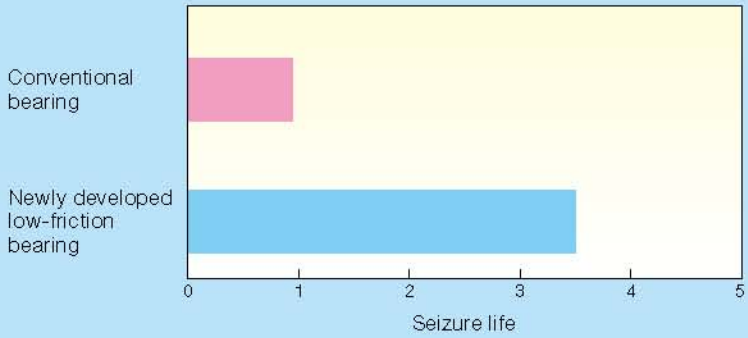
Photo 1 Newly developed low-friction bearings

Fig. 1 Example of a vacuum cleaner suction motor with two low-friction bearings



Test conditions
Bearing: Bore ø8 mm × outside diameter ø22 mm × width 7 mm
Rotational speed: 44 000 rpm
Lubrication: Urea-based grease

Fig. 2 Comparison of friction loss



Test conditions
Bearing: Bore ø8 mm × outside diameter ø22 mm × width 7 mm
Rotational speed: 60 000 rpm
Bearing temperature: 90 °C
Lubrication: Urea-based grease

Fig. 3 Comparison of seizure life

friction between the rolling elements and contact surfaces of the inner and outer ring raceways under high-speed operating conditions has been reduced. As a result, friction loss has been reduced to approximately half that of a conventional bearing (see Fig. 2).

(2) Seizure life increased by more than threefold.

By reducing the amount of friction loss involving internal components of the bearing, the amount of heat that is typically generated in the bearing has also been reduced. With less heat being generated in the bearing, there is less grease deterioration. Therefore, lubricating performance of the grease is maintained for a longer extent. In fact, seizure life performance of this bearing is three times longer than that of a conventional bearing (see Fig. 3).

3. Dimensionally interchangeable

This low-friction, energy-efficient bearing is dimensionally interchangeable with a conventional bearing since it complies with ISO standards for boundary dimensions.

4. Applications

This bearing is suitable for high-speed rotary motors including vacuum cleaner suction motors where there is a strong demand for lower power consumption and longer service life.

5. Summary

This article introduced NSK's low-friction, energy-efficient bearings for use in vacuum cleaner suction motors where a significant reduction in bearing friction loss without sacrificing bearing seizure life performance has been achieved. NSK will continue to respond to the needs of various customers and contribute towards greater energy conservation through the application and development of products that perform with ever higher degrees of efficiency.

Quiet-Running Long-Life Ball Bearings for Fan Motors Operating in High-Temperature Environments

In recent years, as computers become more compact and as audiovisual equipment become larger, small fan motors are increasingly used under extremely high-temperature operating conditions. In order to improve cooling performance, the fans tend to be operated at increasingly higher speeds, which require that the bearings operate at ever higher rotational speeds.

NSK has thus developed a new series of quiet-running, long-life ball bearings for use under elevated operating temperatures. These bearings offer quieter running performance under elevated operating temperatures. NSK also developed a new grease product that is specially formulated to further enhance the quiet-running performance of the new series of bearings (Photo 1).

1. Structure and specifications

This new series of bearing adopts a newly developed low-noise grease that is highly resistant to heat. Additionally, internal specifications of the bearing components have been optimized to reduce friction loss.

2. Features

(1) Improved quiet-running performance and long life at high temperatures

Heat resistance of the grease components—base oil and soap (thickener)—was improved to inhibit grease deterioration under elevated operating temperatures. An optimum blend of grease additives further enhances performance by restricting the generation of wear debris. Combined, these achievements improve the quiet-running performance and extend the grease life at elevated temperatures by twofold in comparison with NSK's conventional bearing for high-temperature environments (Fig. 1).

(2) Improved quiet-running performance

Dispersion properties of the thickening agent were improved by optimizing the grease manufacturing process,

Photo 1 Quiet-running long-life ball bearings for fan motors operating in high-temperature environments

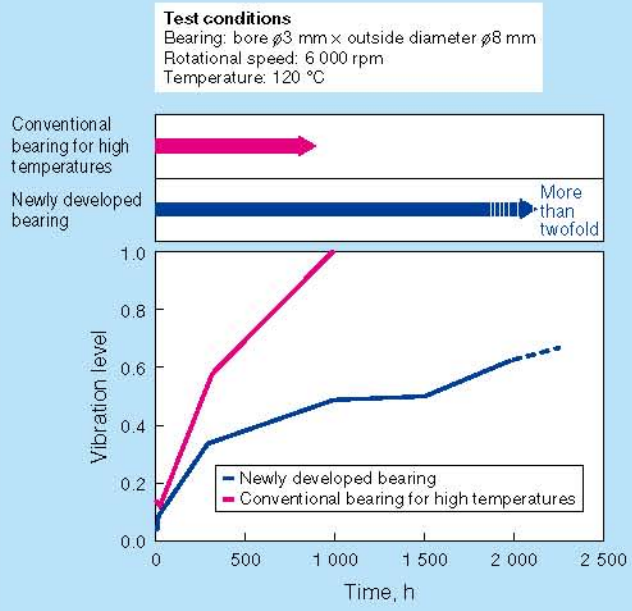


Fig. 1 Comparison of quiet-running performance

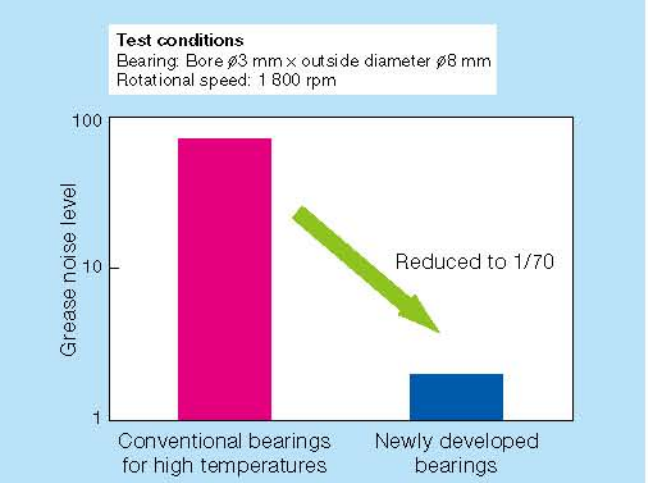


Fig. 2 Comparison of grease noise levels

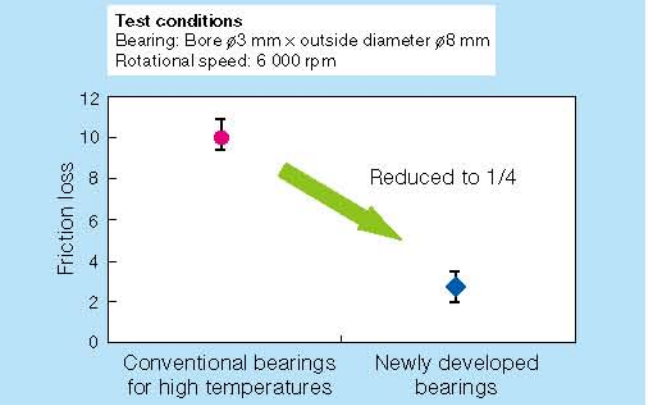


Fig. 3 Comparison of friction loss

which enhances the quiet-running performance of the bearing. Grease noise unique to high-temperature grease was reduced to 1/70 that of NSK's conventional bearing (Fig. 2).

(3) Reduced friction loss

Bearing specifications were revised to address problems associated with friction loss and high-temperature grease. As a result, friction loss was reduced to 1/4 that of NSK's conventional bearing (Fig. 3).

3. Applications

This bearing is used in fan motors that are required to operate in a quiet manner and are typically mounted in audiovisual equipment and home appliances, which include computers, office automation equipment, projectors, etc. This bearing can also be mounted in other equipment or devices that require quiet-running and low-torque performance under elevated-temperature operating conditions or environments.

4. Summary

Although this bearing was initially developed for use in computer and server fan motors, it can be equally mounted in fan motors that are used in similar applications. NSK will work to further expand the use of this bearing in other applications requiring quiet-running and low-torque performance in an effort to meet the needs of current and potential customers.

BSL Series of Ball Screws for Small Lathes

In recent years, small, compound, multispindle lathes are increasingly used to process intricate IT-related components resulting in a dramatic increase in the number of feed functions. Such complexity has increased demand for machines that have a small footprint and requires consolidated, standardized feed components in order to reduce design and production loads as well as lead times.

NSK has developed the BSL series of ball screws (Photo 1) for small lathes to meet these needs with a standardized, simplified screw end configuration and compact nut.

1. Features

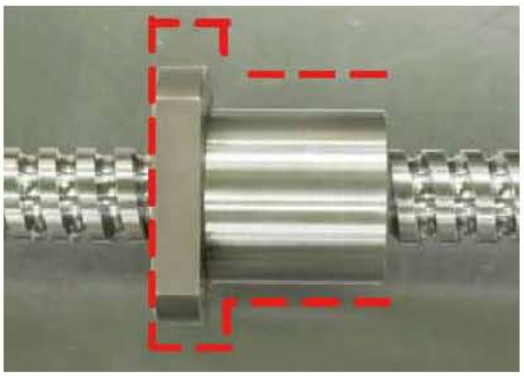
(1) Short lead time

By adopting a flangeless configuration for the screw shaft end, NSK was able to shorten the manufacturing process for this series of ball screw. Lead time was further reduced through the use of standard components, such as NSK's compact nut and a simplified shaft end configuration.

(2) Compact

With the introduction of a new ball recirculation circuit, the ball nut outer diameter has been reduced by up to 24 % in comparison with a conventional tube-type recirculation circuit (Fig. 1).

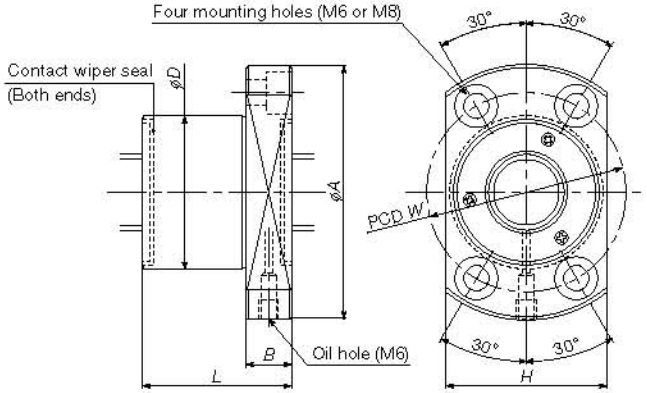
Photo 1 BSL series of ball screws for small lathes



BSL series and the outline (red dashes) of a conventional ball screw nut
Shaft diameter: ø25 mm Lead: 10 mm

Fig. 1 Compact design of the BSL series in relation to a conventional ball screw nut

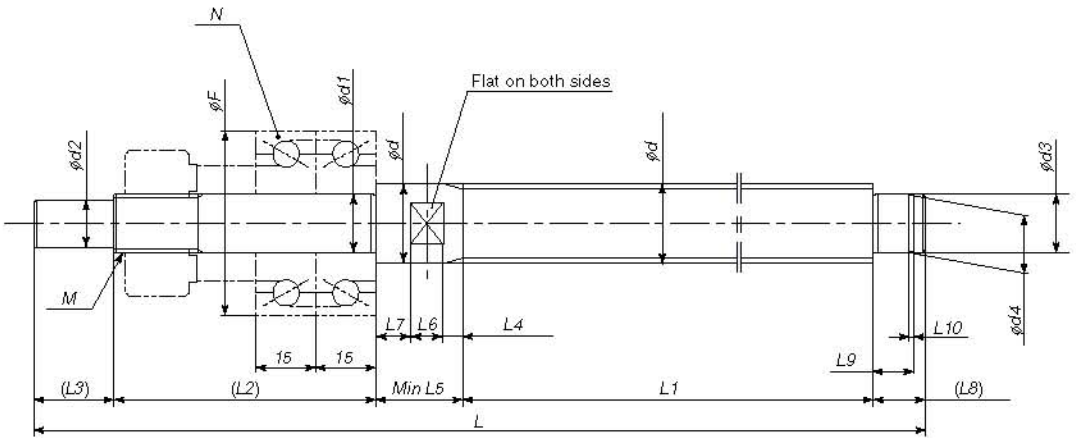
Table 1 BSL series ball screw nut dimensions



Unit mm

Reference numbers	Shaft dimensions		Ball screw nut dimensions					Mounting hole dimensions	
	Shaft diameter	Lead	*D*	*A*	*H*	*B*	*L*	*W*	*X*
BSL2005	20	5	36	63	38	12	37	49	M6
BSL2006	20	6	40	65	42	12	45	51	
BSL2505	25	5	40	65	42	12	38	51	
BSL2506	25	6	43	69	45	12	44	55	
BSL2508	25	8	46	72	48	12	55	58	
BSL2510	25	10	46	72	48	12	65	58	
BSL3210	32	10	61	93	63	18	68	76	M8
BSL3212	32	12	61	93	63	18	77	76	

Table 2 Ball screw shaft dimensions and the reference figure showing the flangeless end configuration of the BSL series



Unit mm

Reference numbers	Shaft dimensions																	Support unit	
	d	*d1*	*M*	*d2*	*d3*	*d4*	*L*	*L1*	*L2*	*L3*	*L4*	*L5*	*L6*	*L7*	*L8*	*L9*	*L10*	Reference numbers	*F*
BSL2005	20	15	M15 × 1.0	12	15	14.3	500	500	66	20	3	20	8	9	14	10.15	1.15	15TAC47B	47
BSL2006											4	21							
BSL2505	25	20	M20 × 1.0	15	20	19	700	700	71	27	3	27	10	14	19	15.35	1.35	20TAC62B	62
BSL2506											4	28							
BSL2508											5	29							
BSL2510											5	29							
BSL3210	32	25	M25 × 1.0	20	35	23.9	1000	800	71	33	6	33	12	15	20	16.35	1.35	25TAC62B	62
BSL3212											7	34							

(3) Excellent resistance to debris

The BSL series uses a plastic seal and an optimized ball groove design for even greater resistance against debris and contamination.

The seal offers 10 times greater resistance to debris in comparison with conventional labyrinth seals.

(4) High load capacity ball bearings

High capacity proprietary bearings, which enable the use of a flangeless shaft end, are available.

(5) Smooth operation

The newly designed ball recirculation circuit, and oversized ball preloading with spacer balls, provide smoother operation of the BSL series of ball screws.

2. Specifications

Tables 1 and 2 illustrate and list the major dimensions, lead accuracy, and preload of the BSL series nut and shaft.

- Lead accuracy grade: JIS 5 (ISO Class P5)
- Preload type: oversized ball preloading

3. Applications

The BSL series is most suitable for lathes and machine tools that require a small footprint.

HTF-SRD Series of Long-Lead Ball Screws for High-Speed and Heavy-Load Applications

In the past, press machines have typically used a hydraulic ram in operations where a heavy load or force is applied. In recent years, the number of all-electric presses using a rotary motor and ball screw has been increasing in response to growing demand for features that include higher molding accuracy, eliminating hydraulic fluid in response to environmental concerns, and curtailing power consumption as an energy-conservation measure. Industry trends are increasingly pointing towards injection molding machines that offer faster mold opening and closing speeds for manufacturing thinner walled parts or products and for improving productivity.

In 2005, NSK commercialized the HTF-SRC series of ball screws for use in high-speed, heavy-load, applications in response to the needs of faster injection-molding machines that were used in molding thinner walled parts. Currently, manufacturers have turned their focus on higher cycles—faster clamping units that open and close molds—for the purpose of boosting productivity. NSK has responded to this need with development of the HTF-SRD series (Photo 1) of long-lead ball screws that offer a fast feed rate of 1 000 mm/second for use in high-speed, heavy-load applications.

1. Features

The HTF-SRD series of high-speed, high-capacity, long-lead ball screws combines a new ball recirculation circuit using an end deflector at each end of the nut (Fig. 1) with the high-capacity design of the conventional HTF series. Design of the recirculation circuit of this series is such that balls flow smoothly in a continuous spiral direction as they leave the shaft groove into the ball nut, which affords the following features:

(1) High-feed rates and high capacity

By adopting an end deflector at each end of the nut and by establishing a long lead measuring a length that is more than half of the outside diameter of the ball screw shaft, this series is able to offer high-feed rates exceeding the maximum 1 000 mm/second. Additionally, the multiple thread screw structure of this series allows for an increase in ball recirculation circuits and the adoption of larger balls that achieve higher loading capacity.

(2) Quiet-running performance

Noise levels for this series have been reduced by 6 dB to

Photo 1 HTF-SRD series of ball screws

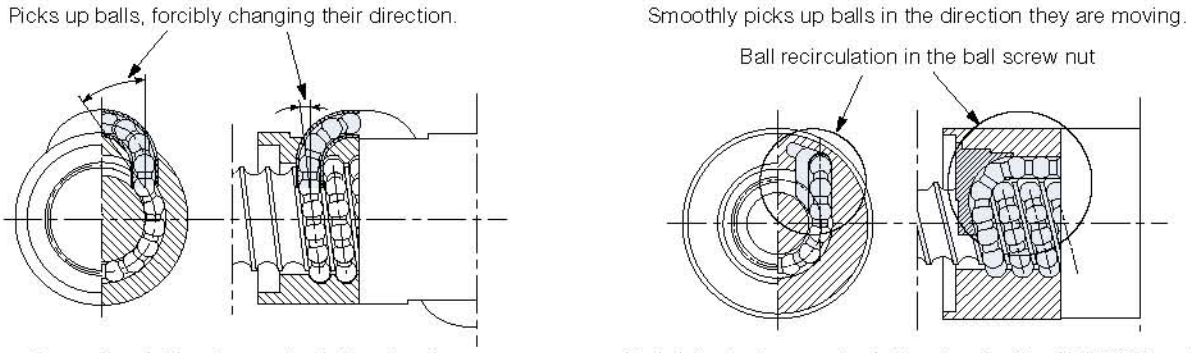


Fig. 1 Comparison of ball return systems of a conventional tube-type recirculation circuit and the end-deflector-type recirculation circuit of the HTF-SRD series

10 dB compared to that of conventional products through the adoption of a new ball recirculation circuit with an end deflector at each end of the nut. Thus, noise was reduced by nearly 1/3 to 1/2. Fig. 2 shows a comparison of noise level test results of the HTF-SRD series and conventional products.

(3) Simple configuration of ball screw nut

The ball recirculation circuit enables the use of a ball screw nut that is cylindrical in shape, which affords the HTF-SRD series superior rotational balance, facilitates the use of a rotating the nut, and allows for the design of simpler housing configurations.

(4) Improved durability under moment loads

Durability of the ball screw under a moment load is greatly improved with NSK S1 resin retaining pieces, which are positioned between each ball to prevent ball jamming resulting from misalignment of the ball screw caused by moment loads.

2. Specifications

Table 1 shows examples of shaft diameters and leads that are available for the HTF-SRD series. Limited d·n values (shaft diameter (d) in mm and rotational speed (n) in rpm) and accuracy of the ball recirculation circuits are as follows.

- Ball recirculation circuit: end-deflector recirculation circuit
- Limited d·n value: 120 000
- Lead accuracy: JIS Ct 7

3. Applications

The HTF-SRD series is suitable for electric injection molding machines; die casting machines; and various carrier device applications.

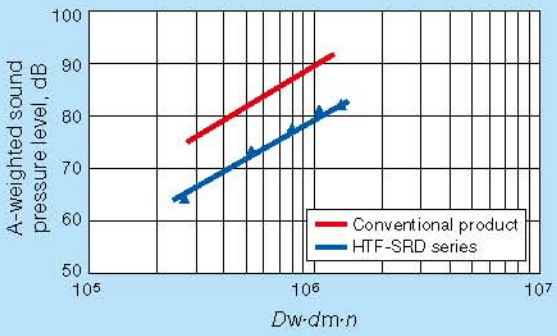


Fig. 2 Noise levels

Table 1 Series lineup

Model numbers	Shaft diameter (mm)	Lead (mm)	Basic load rating (N)		Feed speed (mm/s)
			Dynamic load rating: C_a	Static load rating: C_{0a}	(at d·n = 120 000)
HTF-SRD 5040-6E	50	40	195 000	491 000	1 600
HTF-SRD 5040-8E			255 000	679 000	
HTF-SRD 6340-6E	63	40	291 000	768 000	1 250
HTF-SRD 6340-8E			381 000	1 060 000	
HTF-SRD 8050-6E	80	50	401 000	1 180 000	1 250
HTF-SRD 8050-8E			526 000	1 630 000	

High-Accuracy HS Series of Ultra-Precision NSK Linear Guides

In recent years, electronic and precision equipment have achieved ever-increasing levels of precision and performance. Accordingly, there is demand for higher degrees of precision and motion accuracy from the linear motion guides that are used in machine tools and are used at facilities where such equipment is manufactured.

Applications requiring high precision have typically relied on air slider or sliding guides. However, air sliders suffer from low rigidity and are costly to maintain. Meanwhile, sliding guides lack sufficient high-speed performance and suffer from troublesome maintenance requirements. The result has been growing demand for a linear guide that offers higher motion accuracy.

In a linear guide, where the rolling elements recirculate continuously, errors of motion accuracy that are generated by vibrations due to the passage of rolling elements become a problem when attempting to achieve a higher degree of accuracy. Accordingly, NSK developed and commercialized the High-Accuracy series of ultra-precision NSK linear guides, which significantly dampen vibrations caused by the passage of rolling elements.

The High-Accuracy series of ultra-precision NSK linear guide consists of the High-Accuracy HA series for machine tool applications and the High-Accuracy HS series for use in manufacturing equipment of semiconductors and liquid crystal displays (LCDs). In this article we introduce the High-Accuracy HS series of ultra-precision NSK linear guides as shown in Photo 1.

1. Features

Development of the High-Accuracy HS series of NSK linear guides was based on the conventional LS series, which includes the following features.

(1) Highly precise positioning

The ultra-long ball slider and optimized ball recirculation circuit offers a high degree of accuracy for both the narrow-range of motion accuracy due to vibrations generated when the rolling elements enter and exit the ball slider, and the wide-range of motion accuracy due to running parallelism, mounting inaccuracies of the linear guide, and rail undulation generated by machine table inaccuracies.

(2) Reduced rolling element passage vibration

Rolling element passage vibration has been reduced by one-third that of NSK's conventional series resulting in significantly improved table motion accuracy (Fig. 1).

(3) Higher precision mounting of rails

By deepening the counterbore of the bolt holes, rail deflection, which is due to bolt tightening when mounting the rails to a machine table, was reduced by more than half that of the conventional specification, and rail undulation due to rail deflection was also reduced. Furthermore, straightness accuracy in the longitudinal direction was improved by shortening the bolt pitch of the rail by half that of the conventional specification in order to improve the mounting accuracy.

(4) Lower friction for higher rigidity load capacity

By significantly increasing the number of steel balls used in the ball slider, this series achieves a higher degree of rigidity and higher load capacity without sacrificing low-friction performance.

(5) Compact design

The higher degree of rigidity and higher load capacity of the High-Accuracy HS series affords the opportunity to

Photo 1 High-Accuracy HS series of ultra-precision NSK linear guides

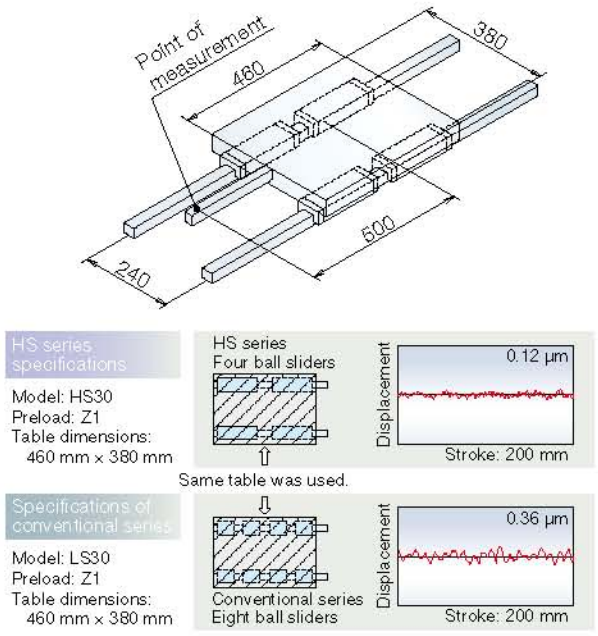


Fig. 1 Comparison of ball passage vibration levels

retrofit current applications for downscaling or designing more compact machine tools.

(6) Stainless steel applications

All-stainless-steel versions of the High-Accuracy HS series are available for users requiring greater corrosion resistance in their applications.

2. Specifications

Table 1 lists the available models and ball slider configurations of the High-Accuracy HS series. Additionally, Table 2 lists the principal dimensions of the square ball slider configuration (AL) as a typical example.

(1) Configurations and dimensions

- The ball slider is approximately twice as long as that of the standard LS series.
- A universal slider design is available that incorporates both through and tapped holes into the flanged slider for a combination of mounting applications from either the top or the bottom of the slider.

Table 1 Two types of the High-Accuracy HS series

Model	Ball slider configuration	
	AL: square type	EM: flanged type
HS15	○	○
HS20	○	○
HS25	○	○
HS30	○	○
HS35	○	○

(2) Accuracy and preload

- Precision with running accuracy to ISO tolerance classes P3, P4, and P5 are available.
- Light preload (Z1) and medium preload (Z3) are available.

(3) Optional

- The NSK K1 lubrication unit, available as an option, facilitates long-term maintenance-free operation.

3. Applications

Development of the High-Accuracy HS series of NSK linear guide was based on the compact LS series, which feature low-friction performance in a low-profile package. Applications for this series include precision measuring equipment requiring high measuring accuracy; wafer processing equipment (slicers), and assembly and packaging equipment (dicers), which require a high degree of processing accuracy; and other various semiconductor and LCD manufacturing equipment.

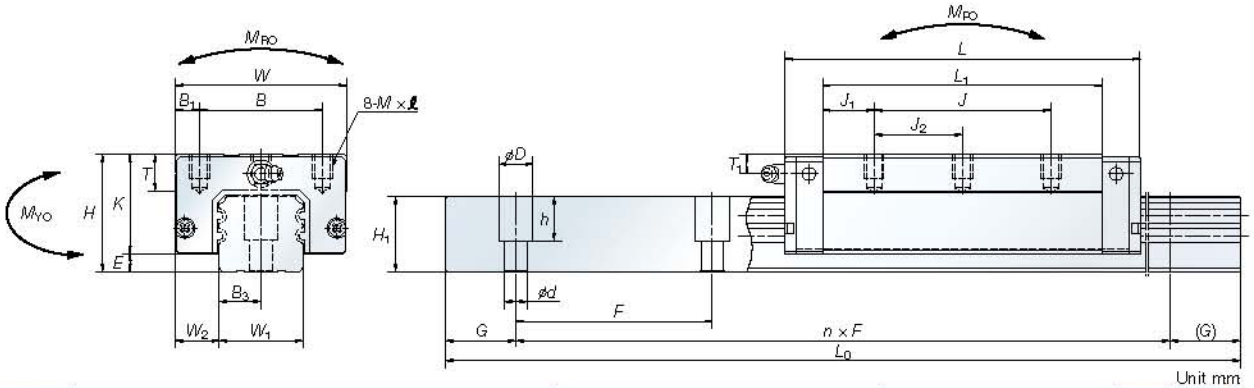
4. Summary

This article has introduced the High-Accuracy HS series of NSK linear guide. .

NSK developed the High-Accuracy HA series for machine tools applications and the High-Accuracy HS series for semiconductor and LCD manufacturing equipment. This series meets the high precision demands of precision equipment using in various industries.

NSK aims to further develop highly precise NSK linear guides to meet future demands of equipment capable of approaching the nanometer scale.

Table 2 Specifications of the AL type of High-Accuracy HS series



Unit mm

Model	Assembly dimensions				Ball slider dimensions												Rail dimensions							Basic load rating					Ball diameter	Mass	
	Height			Width	Length	Rail mounting hole position			Tapped hole						Grease fitting			Rail width	Rail height	Bolt pitch	Hole for rail-mounting bolt		G (Recommended)	Max. length**	Dynamic (N)	Static (N)	Static moment (N·m)				Ball slider	Rail
	H	E	W_2	W	L	B	J	J_2	M×Pitch×ℓ	B_1	L_1	J_1	K	T	Mounting hole	T_1	N	W_1	H_1	F	d×D×h	B_3		L_0max	C	C_0	M_{RO}	M_{PO}	M_{YO}	D_W	(kg)	(kg/m)
HS15AL	24	4.6	9.5	34	106	26	60	30	M4×0.7×6	4	89.2	14.6	19.4	10	ø3	6	3	15	12.5	30	(*) 3.5×6×8.5 4.5×7.5×8.5	7.5	20	2 000 (1 700)	15 300	40 000	199	395	335	2.778	0.34	1.4
HS20AL	28	6	11	42	119.7	32	80	40	M5×0.8×7	5	102.5	11.25	22	12	M6×0.75	5.5	11	20	15.5	30	6×9.5×10.5	10	20	3 960 (3 500)	20 400	52 000	350	590	495	3.175	0.52	2.3
HS25AL	33	7	12.5	48	148	35	100	50	M6×1×9	6.5	126.4	13.2	26	12	M6×0.75	7	11	23	18	30	7×11×12	11.5	20	3 960 (3 500)	32 000	78 000	605	1 090	910	3.968	0.85	3.1
HS30AL	42	9	16	60	176.1	40	120	60	M8×1.25×12	10	150.7	15.35	33	13	M6×0.75	8	11	28	23	40	7×11×16	14	20	4 000 (3 500)	51 500	127 000	1 190	2 120	1 780	4.762	1.7	4.8
HS35AL	48	10.5	18	70	203.6	50	140	70	M8×1.25×12	10	175.6	17.8	37.5	14	M6×0.75	8.5	11	34	27.5	40	9×14×20	17	20	4 000 (3 500)	71 500	172 000	1 980	3 350	2 820	5.556	2.5	7.0

*The standard rail-mounting hole for HS15 is specified as the hole for M3 (3.5×6×8.5). **Dimensions in parentheses apply to stainless steel models.

NSK Linear Guides for Food Processing Equipment and Medical Devices

Food processing equipment and medical devices process products that are taken into or come into contact with the human body. The chief concerns of such manufactured goods that come into contact with processing equipment or devices are cleanliness and safety.

Much like a rolling bearing, steel balls are used in a linear guide for the rolling elements. Additionally, grease or oil lubricants are used to ensure smooth operation. Unlike a rolling bearing, however, the structure of a linear guide is dramatically different in that the guide rail fully exposes the raceway surface (ball groove) to the elements. Furthermore, this structure puts manufactured products at risk of contamination from dripping lubricant or from being splashed directly onto the ball groove. Additionally, the main components of most food processing equipment are fully washed with cleaning agents or sanitizing agents that tend to cause problems related to poor durability or even premature failure of the linear guides due to the deterioration or outflow of lubricant. Moreover, in line with the rapid reduction of environmentally harmful substances in recent years, the food processing equipment industry has been proactively pointing out the harmful effects of lubricants used in food processing equipment.

NSK has addressed these problems by offering a series of linear guides that adopt a highly safe lubricant grease and the NSK K1 lubrication unit, which ensures continually superior lubrication performance and facilitates long-term maintenance-free operation of the linear guide as the standard for devices requiring strictly controlled, hygienic conditions such as that of food processing equipment or medical devices (Photo 1).

1. Features and specifications

(1) Highly safe

NSK provides an incidental food-contact H1 grease lubricant that is in compliance with guidelines that are implemented by the National Science Foundation (NSF) and the United States Department of Agriculture (USDA). The NSK K1 lubrication unit, which has been adopted as an industry standard for food processing equipment and medical devices, and continues to receive favorable marks for maintaining a high level of safety, is in compliance with U. S. Food and Drug Administration (FDA) guidelines.

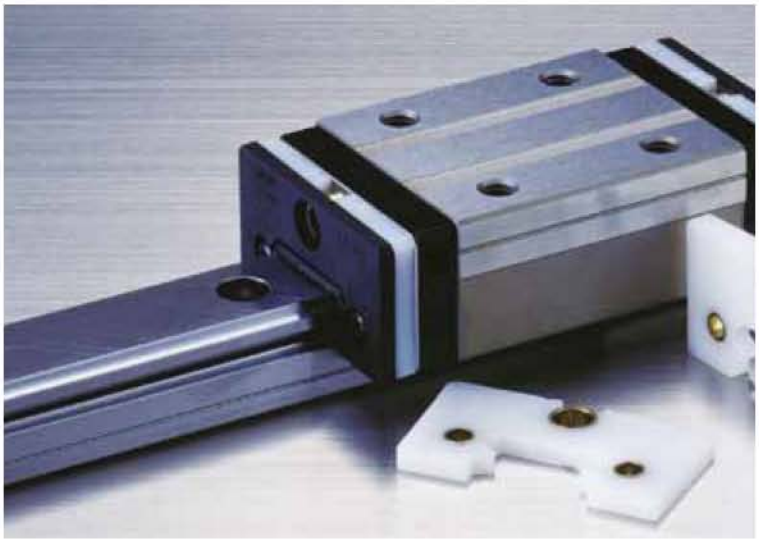


Photo 1 NSK linear guide for food processing equipment and medical devices

Table 1 Endurance test conditions of the NSK linear guide for food processing equipment and medical devices submerged in water

Test sample	LS30AL (material: stainless steel)
Travel (operational test) conditions	Submerged and operated in water for 1 day (24 hours) and operated for 6 days continuously after removing from the water per week
Travel speed	Average 30 m/min
Stroke	400 mm
Load conditions	18 800 N/table (4 700 N/ball slide)
Lubricating conditions	1. Grease for food processing equipment and standard double seal 2. Grease for food processing equipment, NSK K1 lubrication unit, and standard seal

(2) Long-term maintenance-free performance

Standard adoption of the NSK K1 lubrication unit for food processing equipment and medical devices ensures long-term maintenance-free performance of such equipment and devices. Even in environments where grease is washed out by the ingress of water during the cleaning process of food processing equipment, the K1 lubrication unit continues to offer a high degree of lubricating performance and durability (Table 1, Photo 2, and Fig. 1).

(3) Prevent grease leakage and splash

The linear guides are prepacked with the optimal amount of grease to prevent product contamination or contamination of the surrounding environment by grease leakage and splash.

(4) Safety of packaging materials

NSK uses packaging materials that offer a high degree of safety in accordance with standards of the Japanese Food Sanitation Act.

(5) Wide range of series and sizes

Seventeen (17) model numbers of five (5) series are available in order to a wide range of various equipment and devices (Table 2).

(6) Response to the management of environmentally harmful substances

This linear guide complies with the EU Restriction of Hazardous Substances Directive (RoHS).

2. Applications

This linear guide is suitable for devices that are used in operating environments requiring strictly controlled, hygienic conditions, such as that of food processing equipment, food packaging machinery, and medical packaging machinery.

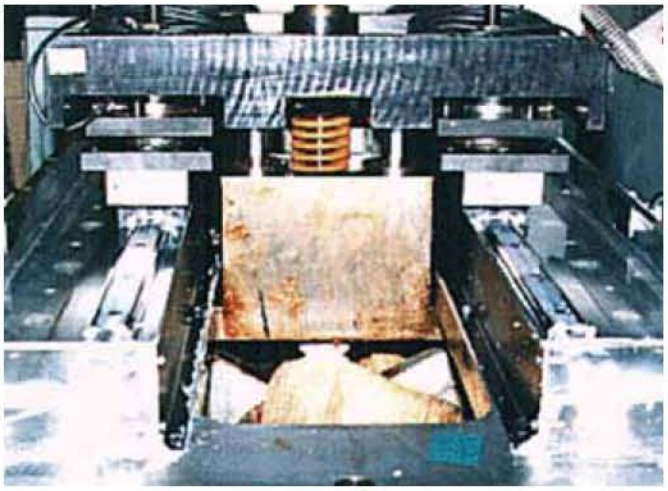


Photo 2 Endurance test of NSK linear guide for food processing equipment and medical devices submerged in water

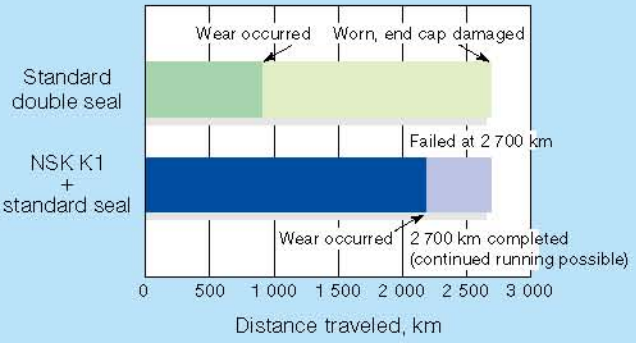


Fig. 1 Endurance test results

Table 2 Applicable series and sizes of NSK linear guides for food processing equipment and medical devices

Classification	Series	Model numbers
General use	LH series	LH15,20,25,30
	LS series	LS15,20,25,30
Miniature	PU series	PU09,12,15
	PE series	PE09,12,15
Wide type	LW series	LW17,21,27

3. Summary

NSK will continue to expand this series of linear guide through further developments to meet the needs of applications that must meet increasingly severe restrictions in regards to safety.

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