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NSK's Environmentally Friendly Products (EXCELLA GREEN™ Grease, GR™ Series Ball Bearings, Linear Guides and Ball Screws equipped with NSK K1®)

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Special Issue on Environmentally Friendly Products and Technologies

Contents

Motion & Control for Global Environment Protection

NSK has been an active participant in the conservation of our global environment. Our actions are in response to the transformation to a sustainable development by means of a recycling-oriented society.

NSK bearings and other NSK products, which are incorporated into a variety of machines, including automobiles, industrial machinery, household appliances, and information processing equipment, have successfully reduced friction and energy loss, thus contributing to the reduction of environmental load through tribology technologies. The functions and characteristics of most NSK products alone classify them as environment friendly products.

The essential role of design and development divisions are to reduce torque, size, and weight, and to further extend product life. This in turn empowers customers with the ability to conserve energy and natural resources. We also believe that it is important to pursue human-friendliness with customers, such as avoiding the use of toxic materials reducing noise levels, minimizing vibrations, and enhancing ease of maintenance and operations.

Some of our more recent achievements include the half-toroidal CVT POWERTOROS Unit, which is noticed as the world's first application of a continuously variable transmission using a rolling mechanism, and an electric power steering (EPS) system. Recognized by customers for its high performance, it will be a popular system of the automobile of the 21st century. Such products are highly reputed as saving energy and increasing fuel economy. We keep developing new technologies for the health of human and environment. In addition, we are proud that our daily efforts for enhancing bearing performance ultimately helps promote conservation of the global environment.

Our mission to the "Century of the Environment" is not limited to compliance with laws that promote fuel economy and nature conservation, but extends to transforming ourselves into an enterprise that exceeds the expectations of society through positive technology development that is focused on the environment, society, and customer needs.

We have compiled this special issue to share with you NSK's environmentally contributory products, in response to consumer needs, with a focus on energy conservation, environmental conservation, clean and friendly technology. We hope this issue gives you a better idea of our commitment, and allows you to take a look at the activities NSK has taken to promote motion and control for global environment protection.

Kyozaburo Furumura
Exective Vice President

Activities Towards Environmentally Friendly Products

Tsutomu Abe, Technology Planning Center

ABSTRACT

In exploring the relation between bearing manufacturers and the environment, NSK's mission was examined. Regarding activities of the technical department in response to environmental issues, the concept of design and development for the environment, and future activity plans are introduced.

1. Introduction

"Sustainable Development" and "Recycling-Oriented Society" are the key words targeting the new century in connection with environmental problems. End users tend to select suppliers whose products have less impact on the environment. Corporate activities that make contributions to improving the environment are essential for business competition and subsistence.

In April 2001, NSK established a Management Innovation Project Team, which organized a new Environmental Stewardship Group. To give environmental activities an extra boost, we reorganized the Global Environmental Protection Committee, which had been formed in 1993 (See Fig. 1). From the viewpoint of technical activities for environmental protection, this paper reports on the activities of the Environmental Product Subcommittee that laterally coordinates and promotes the activities of each engineering and development department at NSK.

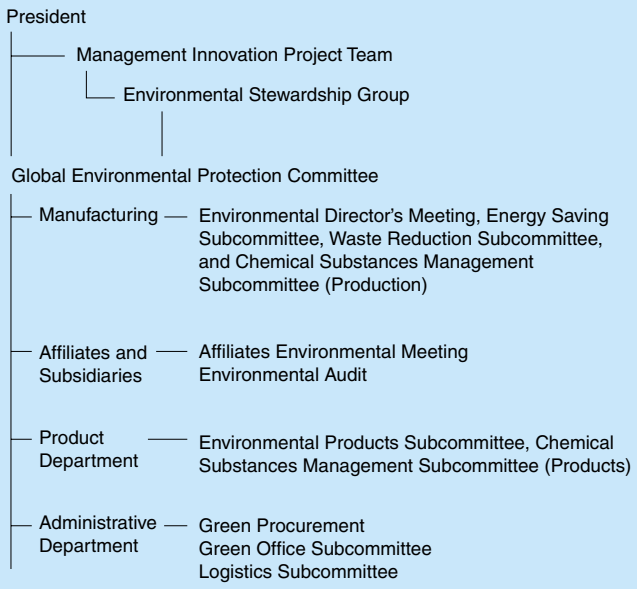

Fig. 1 Organization of global environmental protection committee and action groups

2. Environmentally Sound Activities

2.1 Mission of bearing manufactures for environmental protection

Environmental problems include domestic garbage, dust, NO_X, and others. When the extent of space and the length of time on a broader scale are considered, however, the most significant environmental problems are global problems, such as global warming, ozone layer depletion, and the exhaustion of natural resources. These environmental problems affect the human race, and are a major focal point of the Kyoto Protocol to the UN Framework Convention on Climate Change.

In Japan, CO_2 emissions account for 90% of the greenhouse gases specifically targeted by the Kyoto Protocol, and amount to some 1.2 billion tons per annum—approximately 5% of the total CO_2 emissions worldwide.

Bearings serve as low-friction machine elements in many industrial fields. NSK products, including precision machine parts and automotive parts, as well as bearings, indirectly consume gasoline or some other fossil fuel or electric power in one way or another.

In view of their life cycle, bearings are destined to apply load to the environment more in their usage than in the stages of their manufacture. Therefore, bearing manufacturers have a social responsibility to continuously provide customers with energy-saving products without compromising the natural resources and ability of future generations to meet their own needs.

2.2 Technical viewpoints for environmental protection

NSK product lines, including rolling bearings and linear products, have an environmental protective character that contributes to saving energy and natural resource conservation because of their functions, performance, and properties.

Many of them are made of steel reclaimed from scrapped steel, and after use, they are recycled for use as new steel. Throughout their life cycle from production to final scrapping, they contribute to minimizing environmental impact. When viewed from this standpoint, a great role of NSK technology lies in providing customers with environmentally friendly products to help save energy and

natural resources, and to minimize emissions of harmful substances at the customer's level. Our technology is also required to produce unique NSK products that promote health and safety with low noise and low vibration.

Conversely, the development of environmental protection technologies for the processes of material acceptance, part selection, manufacturing, shipment, and scrapping is also a requirement to prevent environmental load. NSK technologies that have actually been developed to meet these requirements are summarized in Table 1.

NSK's environmentally friendly products are based on breakthrough technologies. For some products, the system itself is changed as seen in the change from a hydraulic system to an electric one, or as seen in the adoption of traction drives. For other products, the material is changed from steel to aluminum, or the heat treatment system is changed by the use of carbonitriding technologies. Structural changes are also made, including a change from solid shafts to hollow ones, including changes in dimensional specifications. Typical embodiments of these changes are represented by our EPS system, half-toroidal CVT, HTF/STF long-life bearing series, and low-torque ball bearings. These are just a few of the products that contribute to greater fuel economy, thus minimizing the environmental impact on natural resources for automobiles, and further support energy savings of electrical appliances for the home.

The development of environmental protection technologies is a steady and inconspicuously technical work, but essential not only for prevention of environmental impact, but also for improving the cost competitiveness of products. The improvement in yield rate, the reduction of stock removal for machining, the shortening of heat treatments, and etc. are small technical achievements, but when practically applied to the manufacture of innumerable quantities of products, the effects can be significant.

The term "environmental management" precisely denotes that modern companies can survive only when they pursue the coordination of ecology and economy.

In 2001, NSK established its own rigid standards for determining which products would be recognized as environmentally friendly products and environmental protection technologies, with which we can then present to our users with confidence. Our standards take into account, and reflect, user evaluations and to some extent are even protected by patents. For such products, we can provide a customer with specific information regarding environmental impact of our products, in addition to providing information that shows how a certain NSK product contributes to environmental protection. Patented products and technologies are converted into sales, which are used as indexes for target control.

Products and technologies protected by patents, so far account for about 35% of total sales and will be increased to more than 50% in three years.

2.3 Development and Design for the Environment

In recent industrial activities for environmental

Table 1 Matrix of environmentally sound technologies : Environmentally friendly products : Environmental protection technologies

Process / Environmental effects	Product planning Features and functions (Outcome for customers)	Considerations for: Material selection Part selection Lubricant selection	Considerations for manufacturing and shipping processes	Considerations for disposal
Energy saving (Electric, gas & fuel consumption)	High speed with reductions in weight, size, and torque CVT, EPS, Hub units Low-torque ball Bearings (GR), Roller clutches with resin cage	Selection of materials and parts having low environmental load Fast-carburized medium carbon carburizing steel	Simplified working; reduction of stock removal for working; shortening of heat treatment time Technology for correcting heat treatment distortion	Recycling of materials: recyclable with less energy
Natural-resource saving (Long life; smaller consumption of natural resources; recycling)	Longer life; integrated into units; smaller size; higher resistance to corrosion and heat HTF; STF bearings; Linear guides with NSK K1™; ROBUST Series bearings	Easily recyclable and light-weight materials Use of hollow shafts	Increase in yield rate; utilization of both main and odds; near net shape working Cold rolling, roll forming, and segment facing technologies	Recycling of materials
Cleanness; healthy & safe (No emission of harmful substances; maintenance; environmental pollution prevention; noise and vibration minimization)	Improved cleanness; tighter sealed state; lower noise; lower vibration; no dust; no need of lubricant replenishment Molded oil™ Bearings Squeak-free bearings; NSK S1 Series™ ball screws	Use of materials and parts free of harmful substances; use of biodegradable lubricants Biodegradable greases; parts of chromium-free material	Use of non-hazardous substances, detoxification of cleaning solutions, and promotion of dry processes working	No toxic leaking even after disposal (by burial or incineration)
Minimization of wastes (Target setup for minimal wastes)	Reusable; easier disassembly design	Selection of reusable or recyclable materials	Minimization and reuse of scraps; simpler packing; use of returnable materials Use of regenerated plastics	Recyclable; reusable

management, emphasis has been on recycling, reduction, and reusing (the three Rs) at production sites. Nowadays, however, the global trend requires designs that are environmentally friendly and take into consideration the full life cycle of products at the initial stage of product planning in technology divisions of a company.

The NSK Environmental Code of Conduct states among other things: "To develop products and technology that will decrease environmental load." For the purpose of honoring our Code of Conduct, engineering and development must work together in a standardized manner. To ensure consistency, an NSK basic policy covering all of its technical divisions and guidelines for individual divisions was established in 2001. The basic policy is as follows:

Basic Policy for Development of Environmentally Friendly Products

For the purpose of supplying products friendly to the environment, we will endeavor to develop products that may cause the least environmental load throughout their life cycle from research and development, through designing, production, and use, until final scrapping. Specifically, we will manufacture products that meet the following standards:

1. Products will contribute to saving energy and reduce impact on natural resources when used by customers.
2. Products will have minimal energy requirements, and minimal impact on natural resources in the process of being manufactured.
3. Products will be manufactured using processes that are free of any harmful or toxic substances, or at least use the safest substances available.
4. Products will contribute to the health and safety of end users with low noise, low vibration, and low dust.

Action guidelines are set up by individual engineering and development groups specialized in bearings, linear products, mechatronic products, and automotive parts, to meet particular needs of customers in their respective fields, and are used for actual engineering work.

The action guidelines are based on the following six topics:

(1) Energy-saving design
(2) Natural-resource saving design
(3) Enhanced service life design
(4) Improved-productivity design
(5) Hazard-free substance design
(6) Healthy and safe design

As a result of our guideline-based activities, two biodegradable grades of grease, including a grade that is used in large volumes, were each certified as an "Environmentally Friendly Product" awarded by the Eco Mark Office of the Japan Environmental Association.

2.4 Introduction of LCA

LCA (Life Cycle Assessment) is a method to quantitatively determine and evaluate the possible environmental load of a product throughout its service life from the raw material production stage, through the manufacturing process, distribution, sale and use, until final scrapping of the product.

Using the LCA, we calculated the environmental load of a half-toroidal CVT POWERTROS Unit (which NSK developed for automobiles). Two cars of a similar type, one was mounted with a half-toroidal CVT POWERTROS Unit and the other was mounted with a four-speed AT. The cars were assessed based on the assumption that both ran 160 000 km.

Calculation results showed that although the transmission system of the CVT-mounted car was twice as heavy as that of the AT car, CO_2 emissions were about 5 tons less owing to the superior fuel economy of the CVT.

LCA is a method still being developed, and undeniably has many bugs to work out. The biggest issue is the lack of an open inventory database covering materials, parts and manufacturing processes.

We hope the LCA Project, which is being conducted by the Japanese Ministry of Economy, Trade and Industry, along with data collection by individual industries, will make a public database available as soon as possible.

At NSK, we will actively pursue in our own efforts to enrich the LCA in order to integrate this method into our product planning as well as for meeting future demands from our users.

3. Conclusion

This report outlined a part of NSK's activities for environmentally friendly products. For our design and development division engineers, environmental protection is not a backward-looking task. It does not simply mean to work to meet fuel consumption restrictions and hazardous substance regulations, but rather engineers are provided with a place for creative thinking where they can unearth business chances by taking conscientious steps towards environmental concerns of the public and end users.

I desire to develop a climate where all NSK engineers fulfill their responsibilities to protect the global environment, which is common to all peoples of the world.

Tsutomu Abe

NSK Products and Technologies Contribute to Energy Conservation

Hiroshi Suzuki, Corporate Research and Development Center
Kenji Takei, Bearing Technology Center

ABSTRACT

Tribology, which is a basic concept of bearing research, is also a field of research that was born from the desire to save energy. Through tribology, rolling bearings have been developed to reduce friction resistance by converting sliding motion into rolling motion, thus contributing to energy conservation. Although progress is constantly being made, NSK accepts the never-ending challenge to make greater reductions in frictional resistance, and to further contribute to energy conservation.

This paper introduces some of the actions taken by NSK to further enhance the energy conservation of NSK automotive products, such as bearings, steering systems, and automatic transmission products, including the CVT.

1. Introduction

Until now, there have been many attempts and a lot of effort expended on technologies that promote energy conservation. The first wave of efforts in energy conservation occurred after the so-called Middle East oil crisis. The second wave came in response to demands for the reduction of CO_2 emissions. The third wave focused more on the need to prepare for the menacing exhaustion of oil resources and on ways to become less dependent on oil. The last wave has arisen from global environmental problems, including the underlying problem of depleting oil resources.

There are two aspects to the current attempts and efforts of energy conservation; one being legal requirements as typically seen in the form of fuel economy regulations for automobiles, and the other featuring voluntary actions taken by individual businesses. Both of these aspects are essential.

As for rolling bearings, energy conservation in the early stage of bearing development meant the reduction of frictional resistance by changing their motion from sliding to rolling. Nowadays, however, energy conservation means to reduce the frictional resistance, and the resulting energy loss, of rolling bearings themselves. In other words, the act of simply changing from sliding to rolling contributed to energy conservation by reducing frictional resistance. But today, rolling bearings are destined to have a greater and more direct impact on minimizing the loss of energy being transferred to the utmost extent possible.

Various positive and significant improvements in energy conservation have been achieved, including the reduction of frictional torque by changing from sliding to rolling bearings, life elongation, downsizing, and the combination of a bearing and its adjacent parts into an integral unit resulting in a compact, lightweight assembly.

NSK automotive products must consume less fuel. For the purposes of reducing fuel consumption, size, weight, and power loss, and for drastically improving overall fuel economy, rapid progress has been made in the development of fuel cell automobiles, as well as hybrid automobiles that can regenerate energy.

It is no exaggeration to say that the current development of all NSK automotive products originates from the need to save energy, or lessen environmental load in a broad sense.

Product development is expected not only to produce products that consume less energy, but is also expected to select materials and parts that cause less environmental load, improve workability and reduce marginal allowances for machining, shorten the heat-treating time in the manufacturing process, as well as to increase yield rate.

The following sections present a brief profile of NSK's products and technologies associated with energy conservation.

2. Conserving Energy Through the Research Field of Tribology

Tribology is the research field most deeply related to rolling bearings, which primarily focuses on the study of friction, abrasion, lubrication, and materials. The term "tribology" was first used in a Jost Committee report to the United Kingdom Ministry of Education and Science in 1966. This report recommended: (1) energy conservation by reducing friction, (2) labor force improvements, (3) lubricating oil-cost reductions, (4) reduction in machine maintenance and part replacement costs, (5) cost reductions for machine failures and problems, (6) reduction in the cost of equipment investments by improving overall machine efficiency, and (7) reduction in the cost of equipment investments by extending machine service life. By implementing these seven goals, estimated annual savings in the UK were 515 million pounds (1.3% of the GNP at that time).

With that recommendation, the UK government advanced the research, development, and education of tribology as a national policy. The study of tribology continues even today in the UK.

In Japan, the technology research center of the Japan Society for the Promotion of Machine Industry, which is under the control of the Ministry of International Trade and Industry, proposed in 1970, with the collaboration of

the Japan Society of Lubrication Engineers, recommendations similar to those of the Jost Committee. The recommendations were edited into two volumes, one titled "Current Situation of Lubrication Issues in Japan" and the other titled "Report on the Research of Actual State of Lubrication," in which it is estimated that Japan can annually save 2 trillion yen (2.6% of Japan's GNP at that time).

Similar to the aforementioned recommendations, in 1977, the Strategy for Energy Conservation through Tribology were set forth in the United States, which pointed out that two thirds of the total energy consumed in all industries in the United States was being wasted in the form of friction and heat[1].

Thus, the promotion of tribological research and development and practical application of its results could lead to greater economical benefits amounting to a few percent of the GNP.

The field of tribological research for rolling bearings has arisen with a single focus on energy conservation, which is also the core technology of bearings.

3. Rolling Bearings Contributing to Energy Conservation

3.1 Pursuit of lower rolling bearing friction

Reducing frictional resistance of rolling bearings is a never-ending challenge. A theory for frictional resistance has been established for tapered roller bearings that run in rolling and sliding contact at their ribs and roller ends. This theory[2] has been used to reduce frictional torque.

Factors of frictional resistance for a tapered roller bearing include:

(1) Rolling friction between the outer and inner ring raceways and rollers
- Friction loss due to elastic hysteresis
- Viscosity resistance of EHL oil film (M_R)

(2) Sliding friction between inner ring rib and roller ends
- Friction by metal contact (M_S)
- Viscosity resistance of oil film

(3) Sliding friction between rollers and cage

(4) Agitation resistance to lubricant

The dominant factors among the above items are M_R and M_S. Frictional resistance, M, of a tapered roller bearing is given by:

$$M = M_R + M_S$$

Improvements in the contact section geometry and surface roughness have been made to reduce M_S, in addition to improvements to reduce M_R in practical applications. Other improvements include the optimization of design specifications for the length, number and contact angle of the rollers, thus resulting in successful reduction in frictional torque without adversely affecting life and rigidity[3].

In particular, for tapered roller bearings used in automobile power transmissions, we have developed new optimum design techniques to achieve lower frictional torque while meeting life and rigidity requirements for specific applications. Reduction of frictional torque by as much as 40% of conventional torque was realized by the use of such specialized design techniques[4].

For ball bearings, we developed new torque designs to lower friction, and developed new contact seals inside the bearings and a new grease to reduce torque. For electric tool motors, ball bearings with reduced torque of nearly 50% were developed[5].

There have been strong demands to improve efficiency of motors in order to reduce power consumption of electrical appliances, including air conditioners and vacuum cleaners. NSK thus developed a low-torque type of bearing for air conditioner fan motors and vacuum cleaner motors.

These types of bearings have the same inside and outside diameters and width as Bearing No. 608, but have improved internal specifications, including ball diameter and PCD. Although the dynamic rated load of the new type is lower, it is designed for lower torque, which is achieved by the use of lithium soap grease. This is in consideration of the fact that bearing life in the market relies heavily on grease life. The torque of such bearings is 40 to 50% lower than that of conventional bearings[6].

3.2 Changing from sliding to rolling bearings to reduce frictional torque

The effects of reducing frictional torque by changing from sliding to rolling bearings can be quite significant for roller followers in the valve systems of automobile engines. In the case of passenger vehicles, drivers usually operate

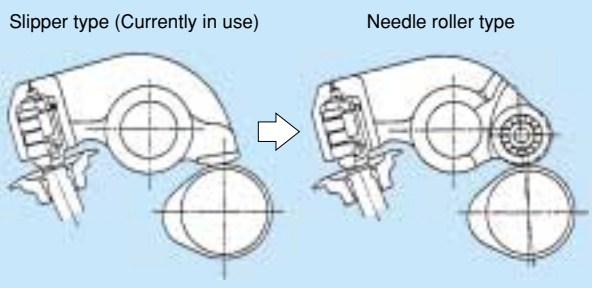

Fig. 1 Needle roller type rocker arm

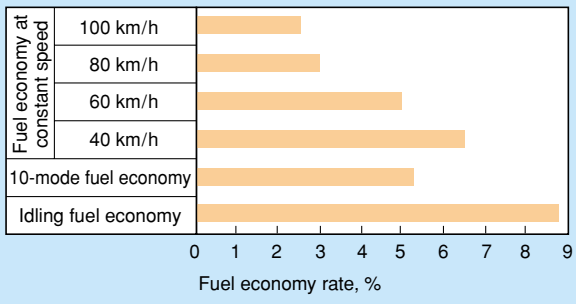

Fig. 2 Example of fuel economy by using needle roller rocker arms

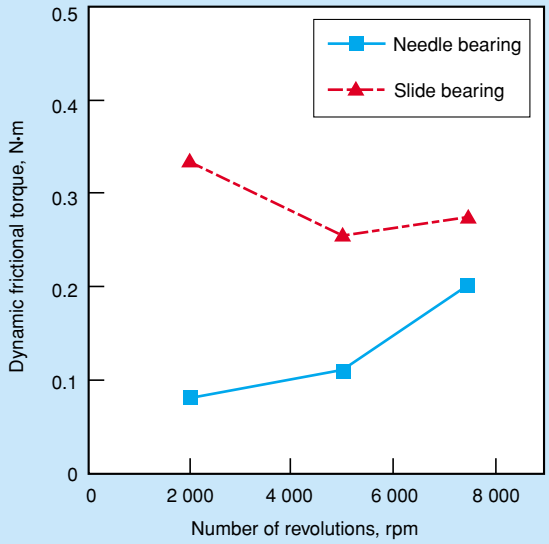

Fig. 3 Dynamic torque comparison of rolling and sliding

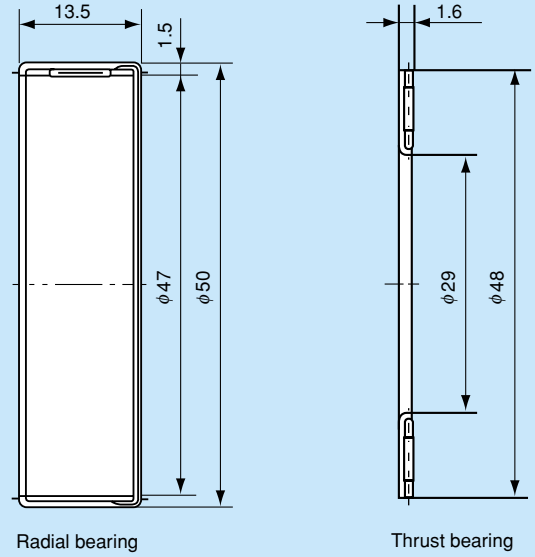

Fig. 4 Thin-section needle roller bearing

the vehicle under low and medium engine speeds. Under these engine speeds, friction of the valve system accounts for a greater portion of entire engine friction. Based on this knowledge, the use of a roller follower (a type of cam follower modified into a roller-type follower) must be effective, something that has clearly been proven.

The use of a needle bearing to support the roller of a rocker arm (needle roller type – Fig. 1) permits rolling contact not only between the needle bearing and the cam but between the roller inside diameter surface and the shaft as well. The outside diameter surface of the roller is crowned for the purpose of preventing offset contact due to misalignment with the camshaft. It is reported that the use of a roller follower can reduce fuel consumption by about 3 to 5% under ten-mode fuel efficiency testing (Fig. 2)[7].

Many slide bearings are used in automatic transmissions (A/T) of automobiles. Replacing slide bearings with rolling needle bearings decreases frictional torque (Fig. 3). Before a slide bearing can be replaced, the needle bearing must be able to perform, rolling with the same dimensions as the slide bearing. Therefore, NSK has developed[8] needle bearings having a wall section thickness as thin as 1.5 to 1.6 mm (Fig. 4).

3.3 Weight reduction of automotive bearings

Overall downsizing and weight reduction of automobiles are needed to reduce fuel consumption. Improvements in automotive bearings made by NSK help automakers meet such goals. Some of our approaches include the following:

(1) Material Development
Develop new materials, long-life materials, and heat treatment processes.

(2) Design Development
Promote optimum designs and development of working processes.

(3) Application Development
Integration of parts into units (unitization), and optimization of bearings in applications.

3.3.1 Downsizing and weight reduction by extension of bearing life

One of the methods for reducing the weight of bearings for automobiles is downsizing by life elongation. Patterns of fatigue that affect bearing life are elucidated by our technical development of fatigue analysis[9], thus the remainder of its life can be estimated. This information is used to extend the life of bearings for specific applications and to contribute to the downsizing of bearings as well as the systems in which they are used.

For internal fatigue, several means are used to reduce nonmetallic inclusions in steel. Regarding the surface fatigue of bearings exposed to contaminants, retained austenite content is increased and fine carbides and nitrides are formed on the surface[10] to significantly extend life and promote subsequent downsizing. It is possible to quantitatively analyze the effects of the concentration, hardness, and size of contaminants upon bearing life[11], and thus make a selection of optimum materials and heat treatments based on results of the analysis. All this contributes to more downsizing and greater optimization[12].

3.3.2 Downsizing and weight reduction by integration into units

For automobiles, the integration of bearings and adjacent parts into units (unitization) is promoted to reduce the weight of the bearings and adjacent structure as well. The unitization of wheel hub bearings (Fig. 5), in particular, has been successful in not only reducing the weight and size, but also in reducing assembly work and improving reliability and maintenability[13].

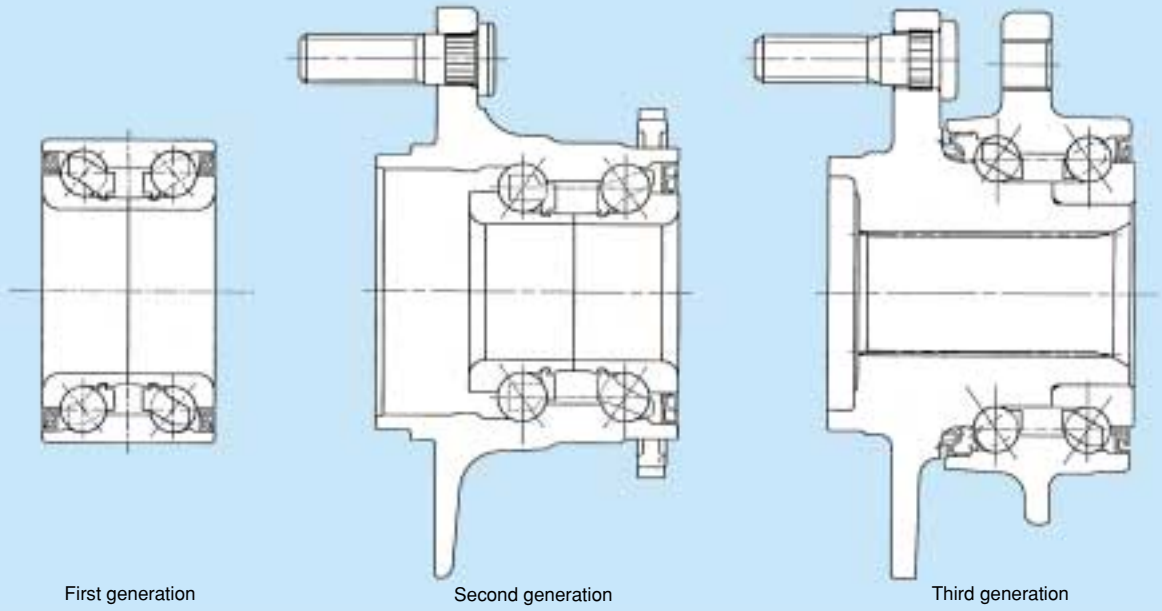

Fig. 5 Hub unit bearings

4. Energy Conservation Approaches for Automotive Power Steering

4.1 Electric power steering

Electric power steering (EPS) (Fig. 6) is a very energy conscious system because it consumes energy only when the driver turns the steering wheel. Energy consumption is as low as approximately one twentieth of that of hydraulic power steering. In addition, no oil is used in the EPS, thereby avoiding environmental contamination at both production and scrapping stages. Thus, EPS is a good example of how a new product can contribute to the protection of the environment[14]. An automobile equipped with EPS can reduce fuel consumption by 3 to 5%[15].

4.2 Weight reduction of steering

Many improvements have been achieved to reduce the weight of the steering column. A typical change was to move from a solid steering shaft to a hollow one. This improvement was also extensively applied to the main upper shaft for reducing weight and costs.

Aluminum or magnesium die-cast brackets are successfully used for weight reduction as well. Another advantage of aluminum or magnesium die-casting is the ease of parts integration. With this advantage, we can attach several parts to a column tube, which cannot be easily formed from pressed steel sheets. Also, some intermediate shafts are formed by aluminum die-casting.

For parts that need to be lightweight, even if sacrificing

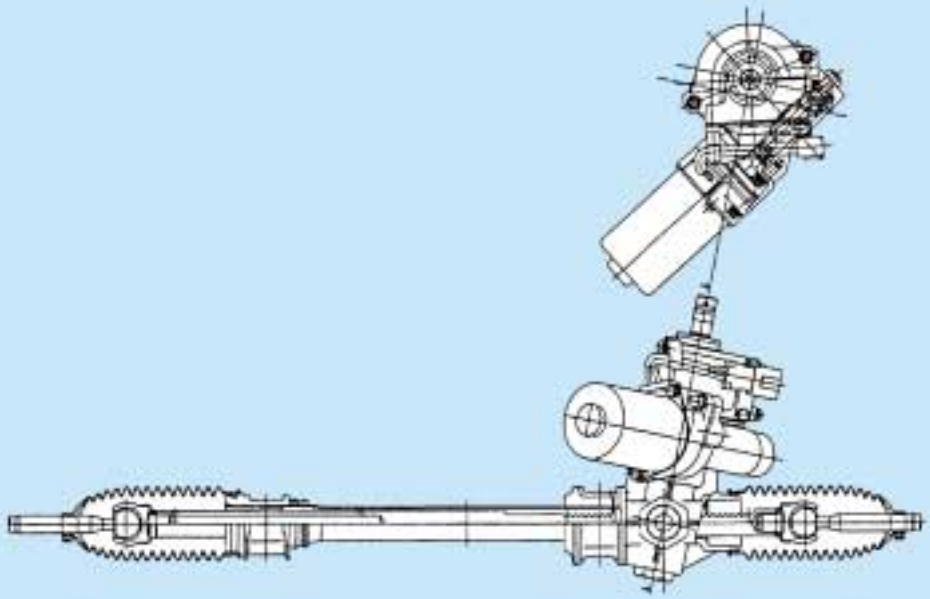

Fig. 6 Electric power steering

cost and size advantages are required, aluminum extrusion molding is used.

It is quite common now to form thin steel plate brackets with ribs or flanges for the purpose of reducing bracket plate thickness without losing strength and rigidity.

5. Reduction of Automotive Transmission Power Loss

5.1 Reduction of one-way clutch idling drag

The one-way clutch of an A/T transmits power in one direction of rotation, but does not transmit power and idle in the opposite direction of rotation. Ideally, this idling drag should be completely eliminated for the purpose of improving transmission efficiency.

In order to give passengers a smooth ride and to eliminate abrupt shifting, smooth engagement and performance as well as long durability of the clutch in shifting to and from idling are essential requirements. To meet these requirements, a spring force needs to be applied to the sprag of the clutch to ensure that the sprag is constantly kept in contact with the outer and inner rings. If the spring force is more than adequate, engagement will be better, but friction during idling may be higher and the resulting drag may be greater, thus resulting in lower transmission efficiency. If the spring force is insufficient, reliability of engagement may be lost. Thus, spring force and engagement are in conflict with each other.

To solve this problem, many quantitative approaches have been made both theoretically and experimentally to reduce the drag[16]. Recently a space-saving and high-efficiency one-way clutch, featuring a roller sprag, was developed. It is lightweight and can keep drag to below one half of the operating range, while maintaining torque capacity.

5.2 Traction-drive type CVT POWERTOROS Unit

NSK developed a half-toroidal continuously variable transmission (CVT) with a traction-drive type POWERTOROS Unit that promotes better fuel economy and assures quick response and smooth ratio changes[17] at various speeds.

This CVT is a result of NSK's unique rolling bearing technologies cultivated and accumulated over a number of years. It was first installed on the Nissan Cedric and Gloria in November 1999, and was the first application of this type of CVT in the world. Also, in comparison to a conventional 4-speed A/T, there is a 10% improvement in fuel efficiency (Fig. 7).

In pursuit of further improvements of CVT efficiency, and to eventually succeed in developing a second-generation half-toroidal CVT[18], research and development have been made on power-split systems, featuring a structure of differential gears incorporating a combination of continuously variable speed toroidal mechanisms and a planetary gear system. The advent of an even more efficient CVT is expected.

6. Conclusion

In this report we have outlined a part of NSK's approaches to develop energy conservation products and technologies. Specifically, these form three basic commitments. Our first commitment to society is to save energy by reducing friction and size of rolling bearings and by improving the performance of machines. Our second commitment is to conserve natural resources by prolonging machine life. Our third commitment is to

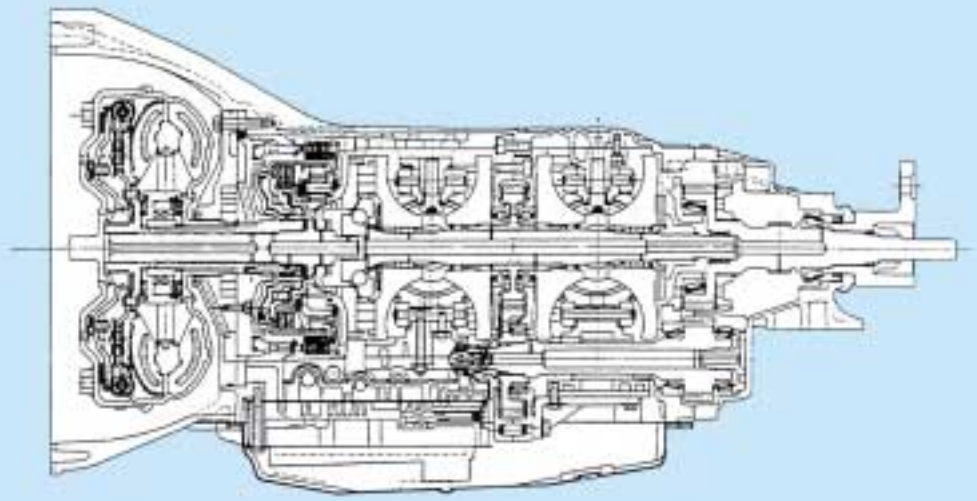

Fig. 7 Nissan Extroid CVT

enhance productivity of human resources by improving machine reliability and by obviating any possible sudden failures. These commitments serve to meet our goals for protecting and supporting the environment on a global scale.

For other automotive parts in our product lines, emphasis is always placed on improving fuel economy, minimizing size, and reducing power loss through improved efficiency or by changing to an electrical system.

All NSK research and development divisions are determined to meet ever-increasing needs for energy conservation.

Hiroshi Suzuki

Kenji Takei

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Development of NSK's Extremely Quiet, Low-Torque, GR™ Series Ball Bearings

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ABSTRACT

Negotiations on the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) were completed in 1997, with Japan committing to reductions in emissions of six "greenhouse gases," including CO_2. Based on this, the law concerning the Rational Use of Energy was revised in 1998, and improvement of energy consumption efficiency of home electric appliances was imposed.

Greater efficiency of various motors, including air conditioner motors, has been accelerated. We developed the GR™ series bearing to be operated quietly with less torque, thus contributing to greater efficiency of motors for use in electric appliances in the home, such as air conditioner motors and suction motors in vacuum cleaners.

1. Introduction

These days, the mass media often discuss issues related to the global environment. In Japan, a new law was enacted that required home electrical appliances to be recycled, starting from April 2001. Environmental problems have thus become a familiar topic in our daily life.

As a consumer, we ask that home electrical appliances provide greater comfort in addition to greater convenience. We ask that an air conditioner, for instance, provide greater comfort, but with lower noise, lower vibration, better temperature control, and functional improvements, such as air-cleaning humidity control.

Moreover, during the past several years, there has been a mainstream requirement of energy conservation combined with reduced costs for bearings, which is in sync with a global trend for greater energy conservation.

It was under these circumstances, NSK developed the quiet, low-torque, GR™ Series bearings for motors. This paper describes NSK's GR™ Series in greater detail.

2. Background of GR™ Series Bearing Development

With the last revision of the Law Concerning the Rational Use of Energy (Energy Conservation Law), a top runner system has been introduced. The top runner system sets up performance standards for various products that are above the performance levels of certain commercialized products on the market whose energy consumption saving efficiencies are highest.

The application of this system will apply to air conditioners shipped for domestic (Japan) use, effective from 2004. This government ordinance will have an especially significant impact since air conditioners (for heating purposes) consume more electric power than any other electrical appliance in the home (see Fig. 1)[1]. (Fig. 2 shows sales of air conditions in Japan.)

To improve the efficiency of air conditioners, various attempts are being made in the fields of air-conditioner components, including compressors, motors and refrigerants. For motors, there is a trend to move from induction types to brushless DC types.

Generally, motor bearings support the rotors, and therefore, cannot avoid mechanical loss. However, by reducing bearing torque, mechanical loss can also be reduced, in addition to added benefits of less noise and vibration of the bearing.

Based on this understanding, NSK developed the GR™ Series, with a focus on eco-friendly bearings. This goes hand-in-hand with the "green" (GR stands for green) concept which we want to convey (See Photo 1).

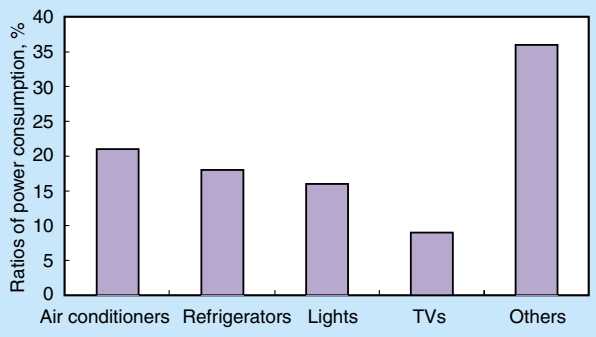

Fig. 1 Ratios of power consumption by products

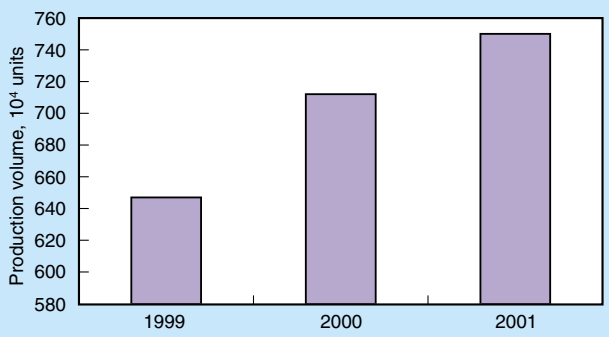

Fig. 2 Production volume of air conditioners

Photo 1 GR™ Series ball bearings

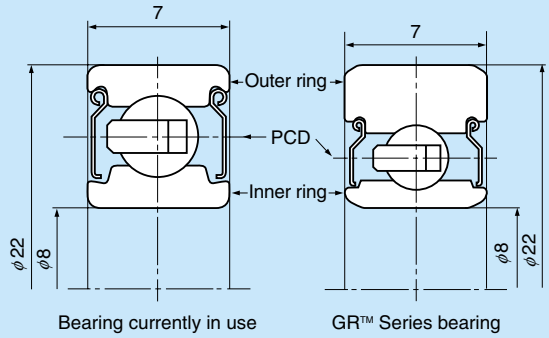

Fig. 3 Construction of GR™ Series ball bearing

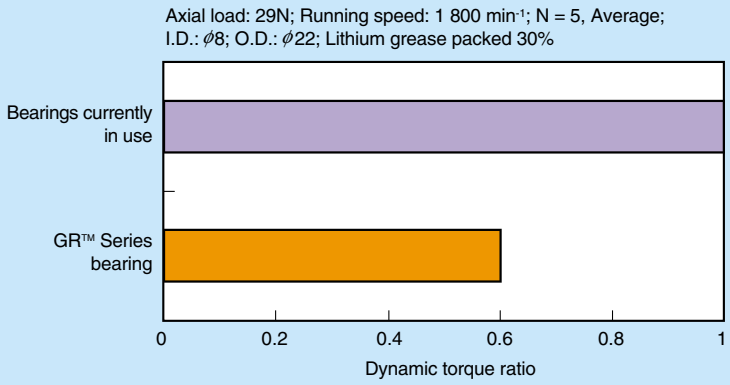

Fig. 4 Comparison of running torque at 1 800 min^{-1}

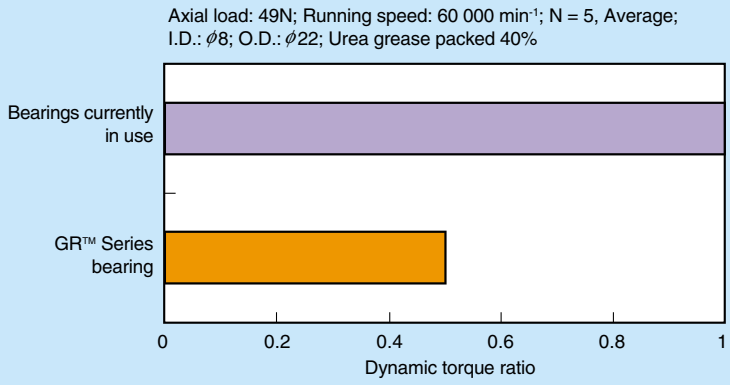

Fig. 5 Comparison of running torque at 60 000 min^{-1}

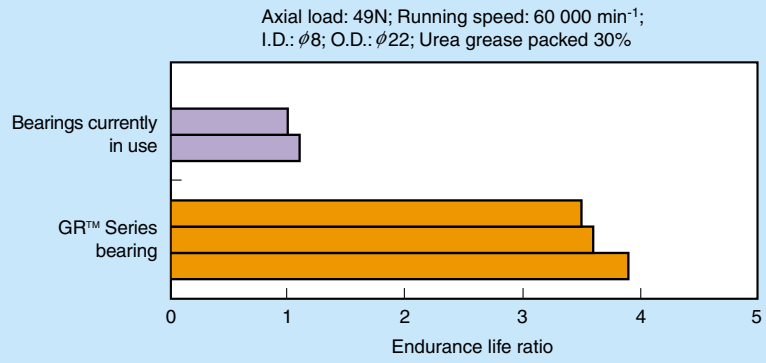

Fig. 6 Comparison of endurance life at 60 000 min^{-1}

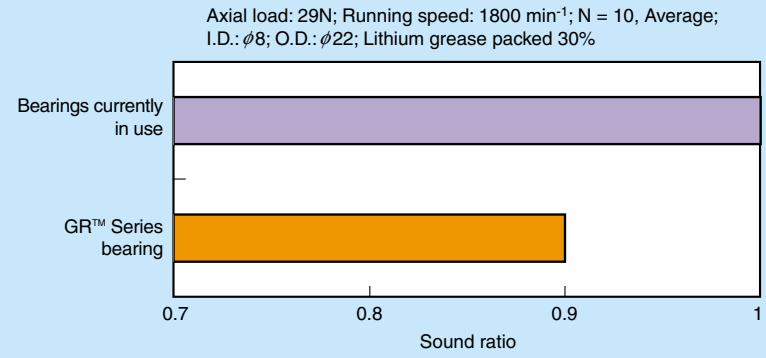

Fig. 7 Comparison of sound levels

Table 1 Boundary dimensions of GR™ Series ball bearings

Bearing No.	Boundary dimensions (mm)		
	I.D.	O.D.	Width
GR693	3	8	4
GR608	8	22	7
GR6002	15	32	9
GR6200	10	30	9
GR6201	12	32	10
GR6202	15	35	11

3. Features of GR™ Series Bearings

Generally, the frictional torque of a bearing (M) consists of a load factor (M_L) and velocity factor (M_V), which is illustrated by the following equation:

$$M = M_L + M_V.$$

The load factor (M_L) consists of the pitch circle diameter of a bearing (PCD), a basic static load rating, and a static equivalent load rating. The velocity factor (M_V) consists of the kinematic viscosity of the lubricant, the running speed, and the PCD of the bearing. The dynamic frictional torque, M, is proportional to the PCD, while being inversely proportional to the diameter of the balls[2].

The GR™ Series bearings are designed to have a small PCD. The diameter of the balls is minimized, with certain limits, so as to avoid adversely affecting ball torque.

The embodiment of these arrangements in the bearing structure has led to the achievement of lower torque and less noise (see Fig. 3).

Features of the GR™ Series bearings in comparison to ball bearings currently in use are summarized as follows:

(1) Dynamic torque is reduced by about 40 to 50% (See Figs. 4 and 5).
(2) Durability life in the highest running speed range is approximately 3 to 4 times longer (See Fig. 6).
(3) Noise level is just as quiet or quieter (See Fig. 7).

Outside and inside diameters, and width of the GR™ Series bearings conform to ISO specifications. This allows easy integration with motors currently in use, therefore avoiding housing design changes.

Although the smaller ball diameter results in a smaller rated load than that of ball bearings currently in use, the GR™ Series bearings are completely free from flaking. This

enhances the durability of bearings used in air conditioner motors and vacuum cleaner motors where bearing life is more concerned with noise and seizure.

4. Prospects for Future Development

The GR™ Series ball bearings are well suited for motors of home electrical appliances such as for air conditioners, vacuum cleaners, and fans. They are also ideal for improving the efficiency of motors of electric devices and instruments in automobiles, especially since there are positive effects in regards to environmental protection, which is of particular importance in recent years. NSK is actively working to further develop the GR™ Series to meet future demands for various sizes of motors.

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Yasuhisa Terada

NSK Products and Technologies for Preserving Natural Resources

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ABSTRACT

Today, an environmentally focused view is very much mainstream all round the world. The idea of "life cycle assessment" is now a key concept for machine builders and users. Consequently, researchers and engineers are seeking products that exhibit lower energy use and extend service life.

A rolling bearing is an important component for any mechanical system because of its role, which is to support a rotating shaft with small frictional losses. Energy and resources can be saved depending on the performance of the rolling bearings selected for a machine.

This article introduces NSK products and technologies with respect to long life, lightweight, and functional integration, which lead to the saving of natural resources.

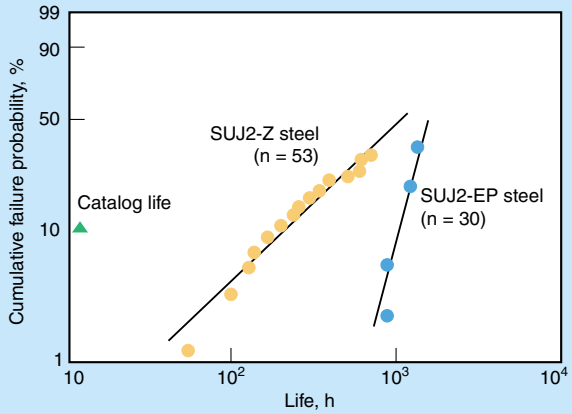
1. Introduction

The latter half of the 20th century saw many countries propose legislation to regulate chlorofluorocarbons and carbon dioxide in response to ozone layer depletion and global warming. Toxic waste and the depletion of natural resources have also become environmental problems of global concern.

In more advanced countries, socioeconomic activities that are enthusiastically pursued after attaining affluence tend to result in creating factors contributing to further disruption of the global environment. The life cycle assessment (LCA) is a concept born out of discussions on what "sustainable development" should be, and places importance on minimizing the environmental load of products throughout their life cycle.

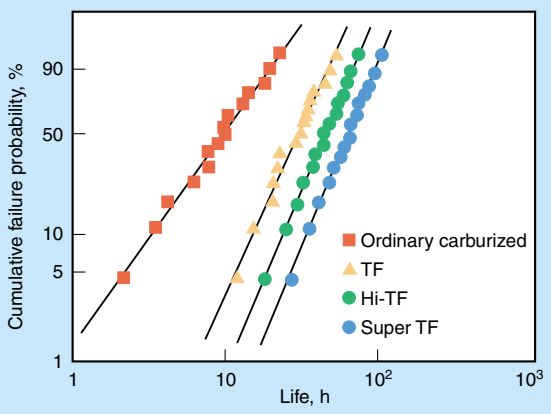
Due to rolling bearings being an essential element of all industries, they are integrated into all machines for transferring rotational energy with minimal energy loss while precisely guiding rolling movement. Rolling bearings are indispensable to machinery and equipment, and fill an additional function of conserving energy, thus promoting conservation of natural resources. Throughout their entire service lives, they dutifully perform their eco-friendly function.

This report spotlights NSK's technologies that serve to promote energy conservation and preservation of natural resources by enhancing bearing service life, making weight reductions, and by unitization of parts. The technologies for enhancing service life cover various materials, heat treatments, surface optimization, design, life estimation, and special environments (See 2.1 through 2.5). Finally, reporting on the technologies for making weight reduction and for combining several parts into one single unit include thickness reduction, downsizing, and unitization (See 3.1 and 3.2).



Test conditions
3 900 rpm
P/*C* = 0.71
Nippon Oil FBK-RO68 forced circulation lubrication
*L*cal. = 12h

Fig. 1 Rolling contact fatigue life of deep groove ball bearings (6206) made of SUJ2-EP on radial type test rig



Test conditions
P/*C* = 0.43 Oil bath lubrication
N = 4 000 rpm
Included contaminants: Hardness: 870HV
Diameters: 74 – 147 µm
Amount: 150 ppm

Fig. 2 Rolling contact fatigue life of tapered roller bearings under contaminated lubrication

2. Enhanced Service Life

2.1 Materials and Heat Treatment

The life of rolling bearings is usually determined by the severity of "flaking," a fatigue phenomenon where a part of the bearing surface peels off in small flakes as a result of repeated stress loads. Rolling bearing life can be determined by researching the causes of flaking and taking preventive measures accordingly. Flaking is a result of two types of bearing defects: internal defects (nonmetallic inclusions in bearing material) and bearing raceway surface defects (dents caused by foreign particles in the bearing lubricant).

Flaking caused by internal defects can be improved with extra-pure and cleaner steel by reducing nonmetallic inclusions that cause defects (Z steel or EP steel), thus extending bearing life (See Fig. 1).

Flaking caused by raceway surface defects can be improved by optimizing retained austenite content in bearing raceway surfaces (TF, HTF, and STF steels) thus reducing stress concentration caused by dents (See Figs. 2 and 3).

Bearings produced with extra-pure and cleaner steel and NSK's TF technologies enjoy a much longer service life. A longer service life places less demand on the environment by requiring less energy to operate. This contributes to environment protection, thus preserving our natural resources.

2.2 Surface Optimization

These key technologies to optimize bearing surfaces, include both surface physical properties (roughness, hardness, and modulus of elasticity) and surface chemical properties (related to molecular layer interactions).

For a surface design to ensure longer bearing life, machining processes (barreling and honing) as well as surface roughness play important roles. A good surface geometry leads to ensure optimum oil film formation, while the machining processes ensure good compressive stress levels and high resistance to abrasion and excessive wear.

These life-enhancing technologies are applied to NSK products, for example needle bearings and cam followers,

Photo 1 AP-treated bearing for aircraft gas turbine engines

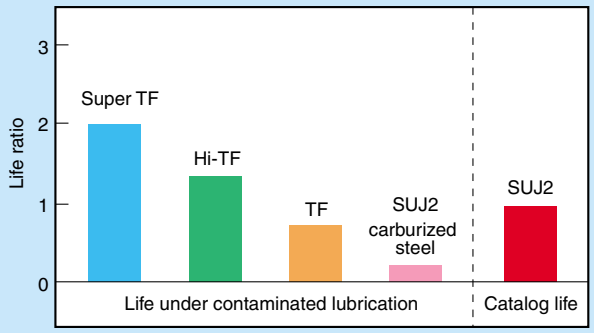


Fig. 3 Comparison of L10 life ratio under debris contamainated lubrication

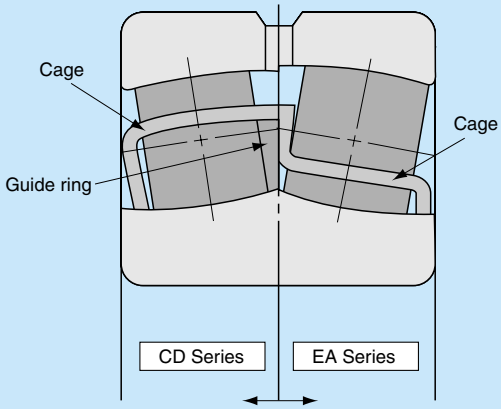


Fig. 4 Spherical roller bearings – EA Series and CD Series

enjoy improved oil film formation and an improved resistance to flaking.

Alternatively, technologies utilizing surface chemical interactions can improve bearing surface affinity to lubricating oil. For instance, a technology that forms manganese crystalline salt on bearing surfaces to which lubricant easily adsorbs, is used for large roller bearings in iron and steel industries to prevent bearing surface smearing. Additionally, surface treatment of bearings with advanced phosphate (AP), such as organic phosphate ester can remarkably increase the endurance of bearings operating under severe conditions of lean lubricity. Photo 1 shows a seizure-resistant bearing whose raceway surfaces were formed with iron pyrophosphate to improve surface affinity to lubricating oil. Service life of the bearing was significantly enhanced with the above surface modifications developed by NSK for an aircraft turbine.

2.3 Design

Longer bearing life is achieved through improvements made in design, machining, material, and lubrication technologies. The life of a rolling bearing is influenced by its dynamic load carrying capacity which is determined by its internal design, as well as the material and lubrication conditions of the bearings. Since global standardization is an attractive feature of bearings, any increase in the dynamic load rating must be achieved by sole modification of internal design, without changing the width, and

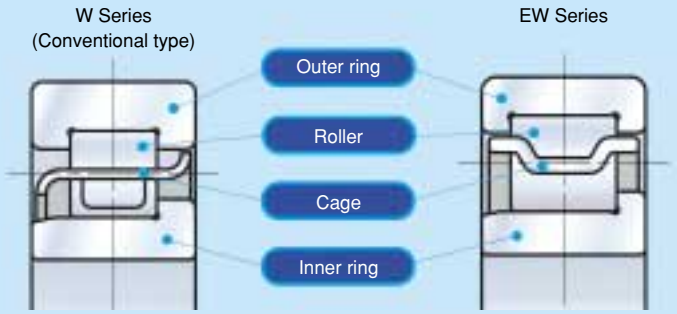


Fig. 5 EW Series cylindrical roller bearings

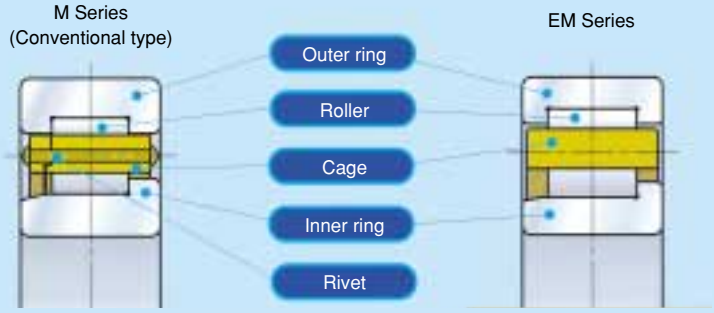


Fig. 6 EM Series cylindrical roller bearings

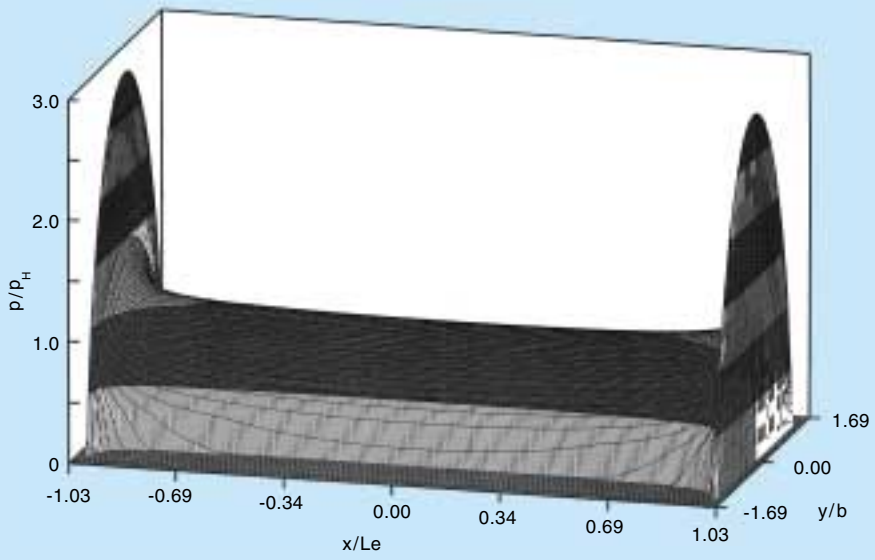


Fig. 7 Analysis of roller/raceway contact surface pressure by MLMI method

outside and inside diameters. In other words, an increase in rating means to design bearings having a maximum number of rolling elements at a maximum size. Theoretically, full-type ball bearings or full-type roller bearings with no cage have a large load carrying capacity, but they also have a high possibility of seizure due to direct contact among their rolling elements. To avoid this, bearings with a cage assembly are most common. An important key to the design of bearings with a cage for extending bearing life, lies in increasing the number of rolling elements by ensuring optimum cage geometry without reducing cage strength.

Standard NSK bearings having a high load-carrying capacity include the EA Series of self-aligning roller bearings, the EW and EM Series of cylindrical roller bearings, and the HR Series of tapered roller bearings. Fig. 4 compares an EA Series self-aligning roller bearing with a comparable CD Series bearing. The EA Series self-aligning roller bearing, having a new, unique roller and cage assembly with no guide ring, which was once considered indispensable, has a 10 to 30% greater load carrying capacity.

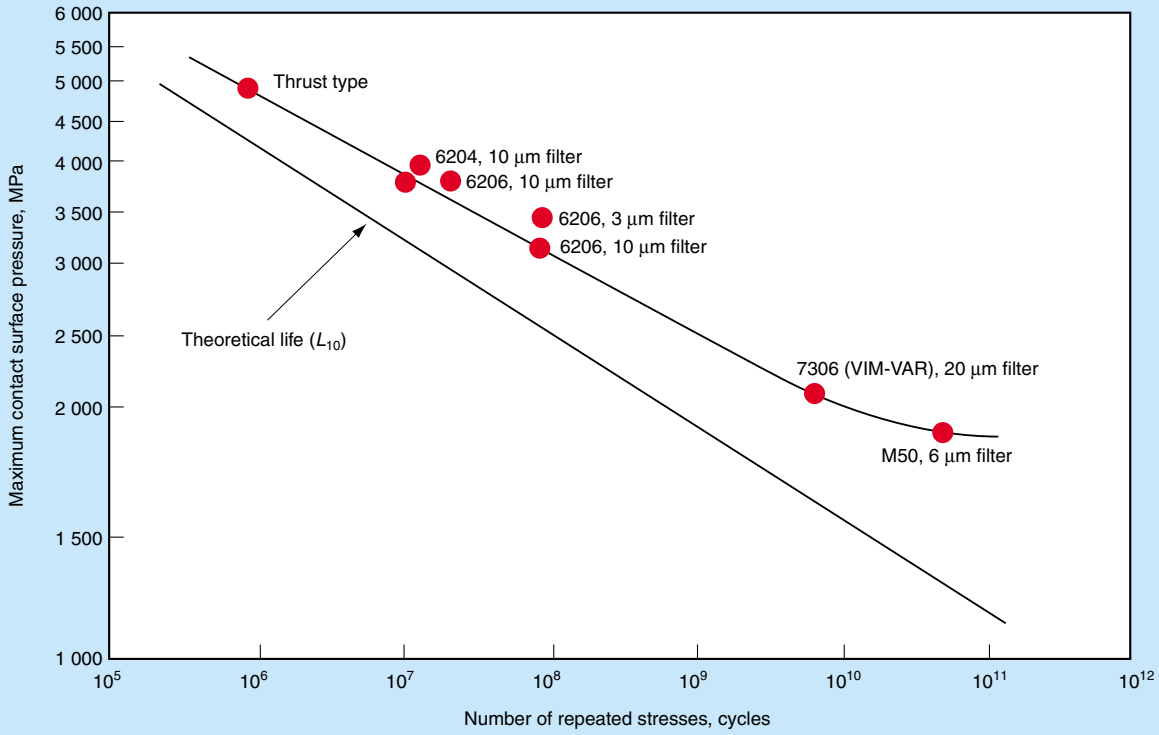


Fig. 8 Summary of life test results under clean lubrication

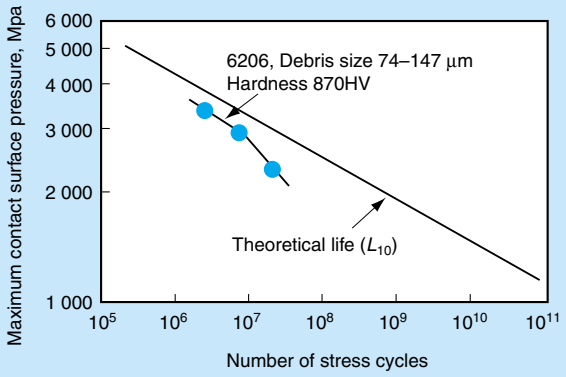


Fig. 9 Test results under debris contaminated lubrication

Figs. 5 and 6 show an EW Series cylindrical roller bearing with a pressed cage, and an EM Series with a machined cage. The EW Series bearing features a new cage design that maintains the same cage strength as the former cage design, but has an increased load carrying capacity of 20 to 30% in comparison to the W Series. The EM Series bearing also features a stronger machined cage and an increased load carrying capacity. The increase in cage strength was achieved by the use of a one-piece cage instead of a conventional type of cage consisting of two riveted pieces. Since both the EW and EM bearings have a higher load carrying capacity, and are supported by optimum cage designs, they can enjoy a higher running speed, and an improved resistance to bearing failure caused by damaged cages.

When there is contact between bearing rings and rolling elements, a local surface pressure called "edge load" can occur at the roller edges if the roller geometry is inappropriate (See Fig. 7), and flaking can develop from the "edge load" point at an early stage. "Edge load" can also take place when the bearing is excessively tilted. To prevent "edge loading" as well as for ensuring longer bearing life, the rollers are crowned. From analysis of contact between the roller element and bearing ring, calculated loads for comparison are required. Therefore analyses never took into consideration various operating conditions. NSK however, introduced early on a high-speed algorithm called the MLMI method and used it as a design tool. Using this tool, bearing engineers can easily examine and determine an optimum shape of crowning.

2.4 Life Prediction Technology

Since rolling bearings are designed to support loads with a small stress volume, actual bearing life tends to be quite varied. The distribution of their life values coincides with the Weibull distribution. For this reason, we usually arrange the life values of our bearings statistically according to the Weibull distribution, and define a basic rated life (hereinafter L_{10} life) as a life value with a cumulative failure rate of 10%.

Since the life of rolling bearings can vary significantly depending on conditions and the operating environment, the quantification of their operating conditions and environment is necessary for determining their L_{10} life by calculation. While the quantification of the operating conditions is easy, the quantification of their operating environment however is very difficult. For this reason, the L_{10} life used to be approximately calculated with the

Fig. 10 NSK ABLE Forecaster

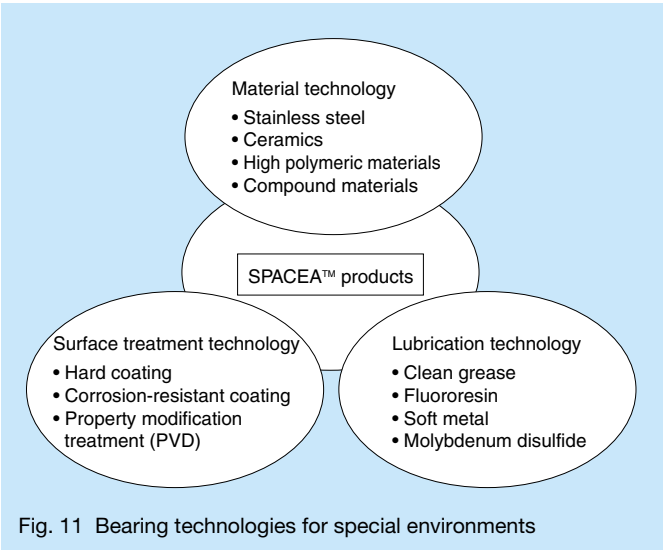


Fig. 11 Bearing technologies for special environments

operating conditions of only load and running speed, with a safety factor set at high.

In comparing L_{10} life and actual life, empirical data of bearing endurance tests operating under ideal lubrication conditions, indicates that actual life is much longer than the L_{10} life (See Fig. 8). This fact alludes to the existence of fatigue limit load that was considered nonexistent in rolling fatigue. On the other hand, normal operating conditions of most bearings include contaminants that reduce actual bearing life by as much as 90% (See Fig. 9).

These test results indicate that bearing life can significantly vary depending on operating conditions, and that the accurate evaluation and the intake of bearing operating environment factors into their life calculations are necessary to accurately predict bearing life.

There are two types of bearing life prediction technologies: (1) Fatigue analyzing technology utilizing X-ray diffraction for individual bearings, and (2) NSK ABLE Forecaster utilizing computer software for a group of bearings (See Fig. 10).

With the fatigue analyzing technology, we can quantitatively determine the most fatigued portions and the fatigue progress of individual bearings that fall under Weibull distribution and predict their remaining life. With NSK ABLE Forecaster, on the other hand, we can accurately predict the L_{10} life of a group of bearings by quantifying their operating environment, based on the conventional life calculation formula (JIS B 1518: 1992).

Accurate prediction of bearing life can serve to improve machine or equipment reliability and help develop critical designs of machines and equipment. Such critical designs contribute to reduced costs and floor space, and promote the use of machines and equipment that use less energy, thus helping to preserve natural resources resulting in greater protection of the environment.

2.5 Life Prolongation in Special Environments

The NSK SPACEA™ Series bearings, ball screws, and linear guide bearings for special environments, including clean bearings, vacuum bearings, and corrosion-resistant bearings for use in semiconductor and liquid crystal manufacturing equipment, are products made by unique materials, lubrication, and surface property modification technologies. These have been developed by NSK to meet demands for longer bearing life under increasingly severe operating conditions. Fig. 11 shows these bearing technologies.

Commercially available fluorine greases have been used for bearings operating in vacuum or clean environments, but their lubricating property is not highly effective and have a tendency to give rise to wear problems. Recently, NSK developed a fluorine grease (LGA), which has an improved resistance to wear and has a life 5 to 10 times as long as that of conventional fluorine greases. On the other hand, bearings operating in vacuum, high-temperature, or clean environments, used to be coated with a silver film or had a fluororesin film baked onto them. This created new service life and outgas problems. Special fluororesin film (LDF) is a fluororesin coat developed to successfully solve such problems. After special treatment of the surface, this film is formed onto the bearing without the use of any binder, and produces less dust with a longer life.

For bearings operating in corrosive environments, stainless steel or ceramic is selected depending on the severity of the environment. For water environments, martensite stainless steel AISI 440C had been mainly used. Recently, corrosion-resistant stainless steel (ES1) having a higher corrosion resistance and a longer rolling life than AISI 440C was developed. ES1 is a highly corrosion-resistant martensite stainless steel that has optimized components, contains less carbon than conventional stainless steel, is free of coarse eutectic carbides, and incorporates alloyed nitrogen. This material is well accepted for applications in corrosive environments. For applications in acid environments, bearings comprising of silicon nitride ceramics have long been used. However recently, bearings comprising of oxide ceramics or carbide ceramics, which have a higher resistance to corrosion, were developed. They also contribute to fewer maintenance requirements of etching equipment.

3. Weight Reductions and Integration into Units

3.1 Downsizing Bearings

Thin wall bearings help promote more compact designs of surrounding components and parts. Even deep groove ball bearings tend to have thinner walls, starting from the 69, 68 and 67 Series (NB7). Along with thin angular contact ball bearings and thin four-point contact ball bearings, these thin deep groove ball bearings have helped reduce the weight and size of the machines in which they are built. In the X-ray tube of a CT scanner (or CAT scan), a very large and thin bearing having an inside diameter of more than 700 mm is used. Since this bearing operates in close proximity to the patient's head, the bearing must not only operate at high-speed, but also do so with very low bearing noise. Fig. 12 illustrates a four-point contact ball bearing and a duplex angular contact ball bearing for the NSK CT scanner bearing. After surmounting the challenge of thinner bearing walls, while achieving greater precision, these bearings contribute to reducing the weight and size of machines.

3.2 Bearing Unitization

The integration of a bearing and its adjacent parts for a machine into one unit can often help reduce the weight and size of the machine. Bearings for automotive hubs are mentioned in this issue of Motion & Control's "NSK Products and Technologies Contribute to Energy Conservation," and will not be described again here. However, let it be said that the unitization of parts helps make further advancements in the automobile industry. In the meantime, Photo 2 shows cage and roller units that have no outer ring or inner ring, but utilize the shaft and housing surfaces as raceways. These bearings can be integrally built into machines so that machine weight, size and design may be significantly reduced.

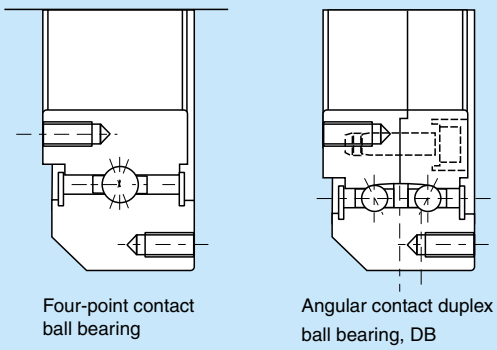


Fig. 12 Thin wall ball bearings for CT scanners

Photo 2 Cage and roller assembly

4. Conclusion

Rolling bearings have not undergone much change in appearance, but their performance has been steadily improved by the progress of design, processing and machining, materials, and lubrication technologies. Since it is the role of rolling bearings to smoothly rotate while supporting a load, manufacturers have been under constant demand to produce bearings with longer life, higher speed, and higher precision. The requirements for preserving our natural resources are nothing but echoes of the constant demands for rolling bearings. Any improvement in the load carrying capacity of rolling bearings extends service life, and promotes the maintenance-free performance of machines, as well as to reduce their weight and size. Any improvement in the high-speed and high-temperature performance of rolling bearings also serves to increase the efficiency of machines. As a result, rolling bearings contribute to saving natural resources by having a longer service life in various environments including high-temperature, high-speed, and vacuum environments. NSK will continuously take steps to develop products and technologies that promote greater energy conservation and preservation of our natural resources.

Yasuo Murakami

Hirotoshi Aramaki

NSK Products and Technologies for Promoting a Cleaner Environment While Preserving Natural Resources

Michiharu Naka, Corporate Research and Development Center

ABSTRACT

In March 1997, NSK announced a new environmental policy that required the company to phase out the use of ozone-depleting substances that damage the stratospheric ozone layer, which results in adverse human health effects.

Specifically, NSK implemented a management program (Official Control Regulations of Products Containing Environmental Load Materials) for steel materials, lubricants, polymeric materials, and surface film products.

Within the European automobile industry, there has been a movement to regulate the use of lead compounds, hexavalent chromium, cadmium, and mercury, which have been described as being carcinogenic and highly toxic. These chemical materials have been used as additives and surface treatment agents for grease and lubricants.

This report introduces official control regulations for environmental load materials contained in NSK products and the recent trend of material regulation. We will also discuss alternative products for lead-based additives and hexavalent chromium, which are the present target of regulations. Furthermore, we will introduce a non-sodium nitrite grease and biodegradable grease that has been developed by NSK.

1. Introduction

In Japan, the 21st century is being labeled as the "Century of the Environment." This reflects the important task of protecting the global environment in the new century. Current environmental issues include global warming, abnormal meteorological phenomena, ozone layer depletion, forest destruction, acid rain, and endocrine disruptors (so-called environmental hormones), are widely discussed in the mass media. These environmental problems are often related to toxic chemicals.

In 1993, with the intention of minimizing the use of ozone-depleting substances, NSK took active steps to fully cease the use of chlorine and fluorine solvents including 1,1,1-trichloroethane, trichloroethylene, and trichlorotrifluoroethane (R-113). These chemicals were used at NSK facilities for cleaning purposes in the bearing production process. As a result, NSK developed alternative cleaning processes using petroleum-based organic solvents or water, and achieved the total elimination of ozone-depleting substances in 1994; earlier than the time limit (end of 1995) set forth by the Kyoto Protocol[1].

The NSK Environmental Protection Guidelines, formulated in 1997, established procedures for minimizing environmental impact, superseding ozone-depleting substances, toxic chemicals, and other pollutants with alternative materials by developing progressive technologies. The Chemical Substances Management Subcommittee (Products) that initiated actions in 1996, conducted research on the pollutants used in steels, lubricants, high polymeric materials, and surface coats. Based on their research results, the committee prepared in March 1997 the "Regulations for the Control of Pollutants Contained in Products," which formed the basis of our current shop standards. These regulations were developed into our pollutant control system, thus our basic policy for increasing reductions was established. Specifically, the regulations inhibited the use of six chemical agents including bromine flame-retardants and chlorinated paraffin. Other actions include: designating seven controlled substances, including mercury, cadmium, lead, hexavalent chromium, arsenic and selenium, whose concentration in products have to be controlled to below a certain level; the surveillance of nine substances, including sodium nitrite, whose concentration need not be restricted for the time being but whose substitutes should be examined; and 20 substances that should be avoided if possible.

2. Regulated Chemical Substances: Trends and NSK Actions

In Japan, recent legislation regulating pollutants are seen in the enforcement of the Product Liability Law, July 1995 (PL Law), and the Pollutant Release and Transfer Register Law, April 2000 (PRTR Law).

The PL Law provides indemnification liabilities of product manufacturers for damage to life, body and/or property of persons caused by defects of their products, and requires them to explicitly state necessary warnings and other product information on their products. As a result of positive conformance by oil and oil product companies to this act, the presence of lead compounds, chlorine compounds, and polycyclic aromatic compounds having carcinogenic, acute or chronic toxicity, that were generally used in many of lubricants, rapidly decreased. In addition, the PRTR Law requires each separate operating unit of a business handling at least 1 ton per annum of any of the designated Class-1 chemical substances, or at least 0.5 tons/year of carcinogenic substances, to have an accurate knowledge of the weight of the chemical substances emitted or transferred to the environment, and

to share such information with the national government through local government offices[2].

The European Union (EU) took steps to extensively regulate chemical substances. In September 2000, the European Commission, which is the executive agency of the EU, adopted the EC End-of-Life Vehicles Directive. This directive prohibits the use of lead, mercury, cadmium and hexavalent chromium in automobiles to be sold starting on July 1, 2003.

In July 2001, NSK re-examined its supplies from outside sources, including greases, lubricating oils, rubber seals, plastic cages, and steels, to see if they contain any of the approximately 1 600 chemical substances listed. For the purpose of attaining the manufacture of products containing no harmful substances, NSK plans to revise the "Regulations for Control of Pollutants Contained in Products."

3. Extreme-Pressure Agents and Lead-Free Grease

Until recently, lead naphthenate, lead dithiophosphate, and lead dithiocarbamate were used as additives in load bearing grease because of their excellent performance as extreme pressure agents and anti-wear agents. These lead compounds, however, are carcinogenic and have acute or chronic toxicity as mentioned above and are regulated by the PRTR Law. Recently, oil companies and grease manufacturers have been actively inclined to discontinue the manufacture of grease containing lead additives, offering alternative grease to users. NSK has examined all of some 700 grades of the greases and lubricating oils currently in use at NSK to find that only six grades of lubricants, including grease for rolling bearings, CVJs, and automotive steering systems are still formulated with lead additives. These greases, as development and formulation of substitutes has already been completed, will be fully terminated by August 2002.

Fig. 1 shows measurements of the dynamic frictional torque of NSK-developed NA3 grease containing lead-free additives. NSK developed NA3 grease especially for HDD actuator units. It is completely lead-free and its frictional torque performance and outgas performance are superior to comparative greases currently in use.

4. Hexavalent Chromium

The shield or the core metal of the rubber seal of a rolling bearing is made of a galvanized steel plate. The galvanized steel plate currently in use is surface-treated with chromate for a better appearance and improved resistance to rusting. Since hexavalent chromium is used in the chromate treatment, a very small amount of hexavalent chromium remains in the galvanized surface and may leak from the surface when exposed to surrounding acidic atmosphere. NSK evaluated the corrosion-resistant performance of tin-plated steel plates and galvanized chromate-free steel plates and confirmed that the tin-plated steel plates and galvanized chromate-free steel plates could serve as substitutes. Photo 1 shows the bearing appearance of a bearing shield after a rust test.

5. Sodium Nitrite

Sodium nitrite is a typical crystalline rust-preventive agent capable of protecting metal surfaces against rust by forming a film on metal surfaces, and is often used in grease. It has a long history as a preservative and is

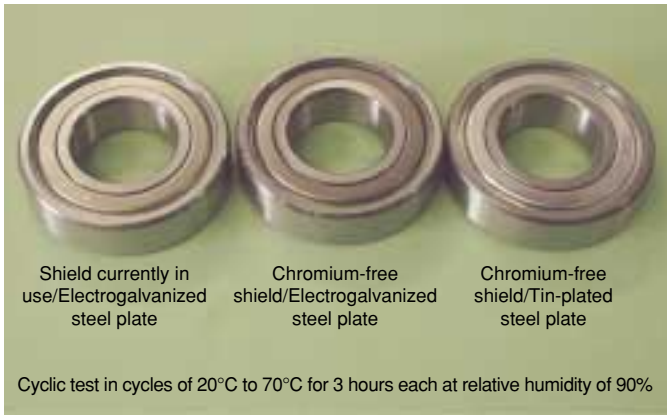
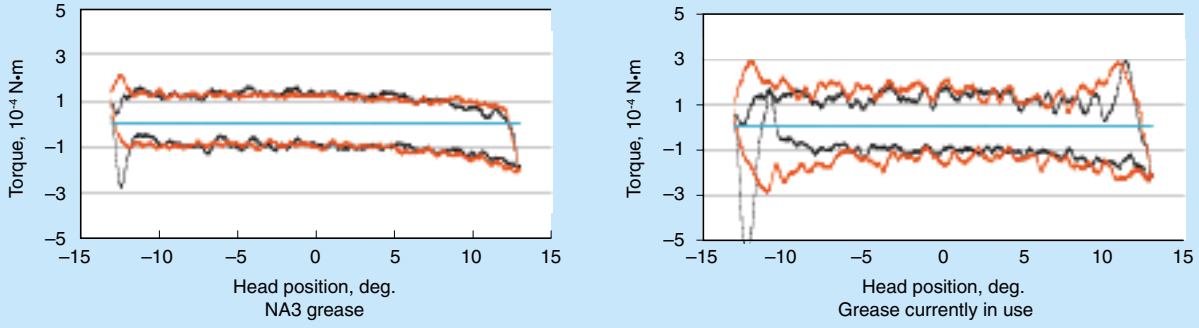


Photo 1 Bearing appearance after 1000 hours of shield rust testing

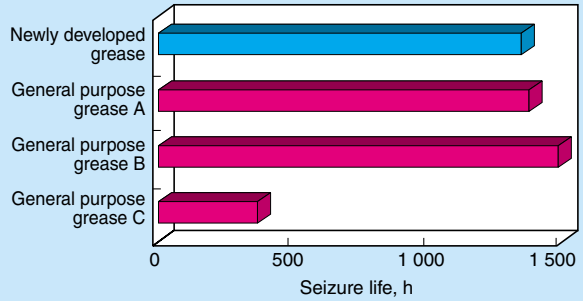


Test conditions
Test bearings: ϕ12.7 mm × ϕ7.938 mm × 3.967 mm Oscillation angle: 26 deg Reciprocation time: 20 min

Fig. 1 Dynamic friction torque measurement results of NA3 grease

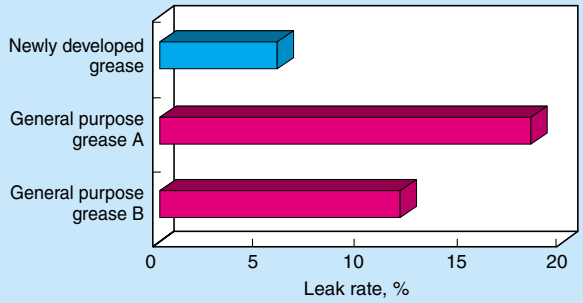
Table 1 Composition and properties of test greases

	Newly developed grease	General purpose grease A	General purpose grease B	General purpose grease C	Test method
Pollutants	None	Sodium nitrite	Sodium nitrite	Sodium nitrite, lead compounds	
Appearance	Light brown	Amber	Amber	Amber	
Thickener	Lithium soap	Lithium soap	Lithium soap	Lithium soap	
Base oil	Mineral oil	Mineral oil	Mineral oil	Mineral oil	
Base oil kinematic viscosity, 40°C mm²/s 100°C	130 12.2	140 10.5	75.0 8.0	50.9 6.5	JIS K 2283
Worked penetration, 60 W, 25°C	275	273	235	278	JIS K 2220 5.3
Dropping point, °C	181	182	185	180	JIS K 2220 5.4



Test conditions
Test bearings: Outer diameter 25 mm, Inner diameter 62 mm, Width 17 mm
Running speed: 10 000 min^{-1}
Ambient temperature: 120 °C
Axial load: 98N
Radial load: 98N
Amount of packed grease: 35% of available space

Fig. 2 Seizure life test results



Test conditions
Test bearings: Outer diameter 25 mm, Inner diameter 62 mm, Width 17 mm
Running speed: 10 000 min^{-1}
Ambient temperature: 120 °C
Axial load: 98N
Radial load: 98N
Amount of packed grease: 35% of available space
Duration of test: 20 h

Fig. 3 Grease leakage test results

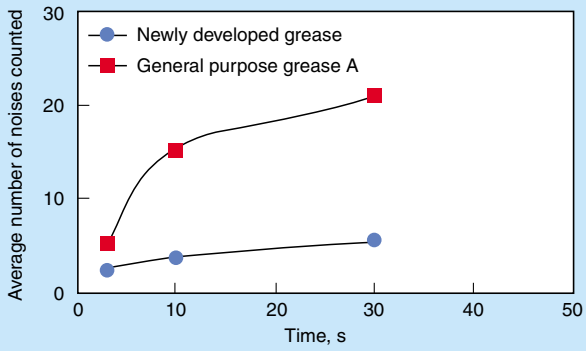
currently used as a preservative in foods. In the presence of Class-2 amine, however, sodium nitrite has a tendency to form nitrosamine, which is carcinogenic. The possibility of its restriction by the EU is imminent.

Among general-purpose greases used for bearings whose operating temperatures are around 100°C, lithium soap greases formulated with mineral oil are most often used. Sodium nitrite is added as a rust preventive to most popular mineral oil-based lithium soap greases. Considering the trend of chemical substance regulations that are likely to be enforced in Europe, NSK and a grease manufacturer jointly developed a mineral oil-based lithium soap grease, free of sodium nitrite ahead of other bearing manufacturers. Table 1 lists the composition and properties of the newly developed, sodium-nitrite-free grease. This grease has leakage performance and bearing sound performance superior to, and seizure life performance and rust preventive performance equivalent to, conventional general-purpose greases. The seizure life test results of deep groove ball bearings are shown in Fig. 2, their grease leak test results in Fig. 3, and their sound measurement results in Fig. 4. At the end of 2001, we started the application of this newly-developed grease to bearings for the European market.

Sodium nitrite added to grease is also known to be very effective for suppressing flaking, along with structural whitening, which began to reveal itself in automotive electrical instrument bearings from around the mid '80s. Seeing that the use of sodium nitrite is likely to be restricted in the near future, NSK also developed a sodium-nitrite-free grease, HA1, for automotive electrical instrument bearings.

6. Barium Sulfonate

Barium sulfonate is used in many rust-preventive oils and greases for its excellent rust preventive performance. However, water-soluble barium compounds are regulated by the PRTR Law when their concentration in rust preventive oil or lubricant exceeds 1%, and also falls under water discharge regulations in some states in the U.S. Barium sulfonate used in rust preventive oils and lubricants is not water-soluble and is not directly subject to regulations, but has a possibility of producing water-soluble barium salts in waste water treating processes[3]. The rust preventive oils currently in use at NSK plants in the U.S. are barium-free because a change of their additive from barium sulfonate to calcium sulfonate, which was already accomplished some time ago. Considering possible strengthening of regulations by the EU in the future, NSK will gradually switch all rust preventive oils currently in use at all non-U.S. plants to barium-free rust preventive oils.



Test conditions
Test bearings: 15 mm O.D., 35 mm I.D., 11 mm wide
Running speed : 1 800 min^{-1}
Ambient temperature : Room temp. (20 to 25 °C)
Number of bearings measured : 30
Amount of packed grease : 30% of available space

Fig. 4 Bearing sound measurement results

Some of the solvents we use to dilute solvent-soluble rust preventive oils contain 1,3,5-trimethylbenzene or xylene, both of which fall under the PRTR Law. NSK is in the process of switching such solvents to those that comply with the PRTR Law.

7. Biodegradable Greases

Biodegradable grease is grease that is easily decomposed by microorganisms into harmless carbon dioxide and water when leaked into the ground, a pond, or a lake. More specifically, a grease that meets the following standards can be registered as a biodegradable grease (Type No. 110) with the Japan Environment Association, upon which it can be certified as an Eco Mark Product awarded by the Eco Mark Office of the Japan Environmental Association4):

- Does not contain EDTA and nonylphenolic surface active agents;
- Biodegradability measured in accordance with the OECD chemical product testing guideline 310B or 310C, or with the ASTM D5864 process, is not less than 60% in 28 days; and
- Satisfies the requirement that the LC50 value at a 96-hour acute toxicity test on fish measured in accordance with JIS K 0102 or OECD 302 process must be not less than 100 mg/l.

The biodegradability of greases largely depends on the properties of their main constituent base oil. Vegetable oils including rape oil, as well as ester-based synthetic oils, which tend to hydrolyze easily, show a high biodegradability[5]. Our NS7 grease that has been used in many bearings for electric and information equipment was certified as an Eco Mark Product in September 2001, and our ENS grease, which has been used in large amounts in bearings for electric engine systems, was also certified as an Eco Mark Product in November 2001. Our NS7 grease, developed in 1975, and ENS grease, developed in 1980, are formulated with an ester-base oil, lithium soap, and urea compound (added as a thickener). EXCELLA GREEN™ (trademark pending) represents both NS7 and ENS greases, which are NSK's flagship products for use with NSK bearings.

8. Conclusion

The measures NSK has taken thus far to reduce pollutants contained in NSK products have been presented above. Our resolve is to develop products and technologies that help promote a cleaner environment. We hope you have gained a better understanding and have a clearer picture of NSK's commitment to environmental protection. You can rest assured that when you use NSK products, you are helping to promote a cleaner environment while preserving natural resources.

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Michiharu Naka

NSK Products and Technologies Contributing to Low Noise and Low Vibration

Banda Noda, Corporate Research and Development Center

ABSTRACT

This article discusses the recent trend of products and technologies that offer greater reductions in noise and vibration in rolling bearings and precision machinery parts, which are the chief products of NSK.

In the first half of this article, we deal with typical sound and vibration problems including race noise of rolling bearings. In addition, we will introduce new NSK technologies that reduce noise and vibration. Finally, we introduce the "NSK S1 Series™" of ball screws and linear guides and describe their excellent sound and vibration performance.

1. Introduction

Noise and vibration have been spotlighted along with dioxin and atmospheric pollutants in the "Permissible limits of, and measuring methods for, the harmful substances designated by the national Japanese government"; the impact of noise and vibration upon the health and safety of the users environment is known to be significant. Therefore, many efforts have been made to minimize noise and vibration from machines and mechanical equipment. This report outlines the noise and vibration of rolling bearings and precision machine parts, which are representative products of NSK, and describes recent approaches made by NSK to reduce such noise and vibration.

2. Reduction in Noise and Vibration of Rolling Bearings

A rolling bearing is a relatively simple machine element consisting of only several parts including rings, rolling elements, and a cage. However, this simple element produces more than ten types of noise[1]. The most basic noise among them is race noise, which is inevitably produced from all bearings as they operate. Race noise is characterized by a smooth, continuous sound. Other sounds of the rolling bearing arise due to the rolling bearing structure, when mixed with the race noise, are often heard as harsh noises.

For this reason, we will treat each noise and vibration as a separate subject, and discuss the corrective measures.

2.1 Reduction of Race Noise

The race noise of a rolling bearing is fundamental to the bearing, but its level can be a problem in bearing applications where quietness is required, such as with electrical home appliances and computer-related equipment.

Among various electrical home appliances, those that require greater quietness are air conditioners and air cleaners, which are often operated all day and night. The level of vibration (which is the source of race noise) has been improved for ball bearings having an inside diameter of 8 mm (See Fig. 1)[2], which is the most common size for fan motors of air conditioners and air cleaners. The improved vibration level of ball bearings has greatly contributed to the quietness of recent air conditioners.

Information systems hardware and related components with rolling bearings include hard disk drives (HDD), laser beam printers, and cooling fan motors for IC boards, CPU, and housing etc. For HDD spindle motors, in particular, the noise and vibration quality of bearings has noticeably improved. These bearings have also been responding to meet greater performance requirements for improved torque, impact resistance, and long-term reliability, in addition to less noise and vibration. They also represent state-of-the-art technologies, among other bearing technologies, in all aspects of design, lubrication, material, machining, and processing.

The race noise of a bearing is considered to have origins in very small irregularities in the surface (waviness) and roughness of the raceways and rolling elements of the bearing. The minimization of such irregularities is the most basic approach to take in reducing race noise. However, even today's excellent bearing machining and

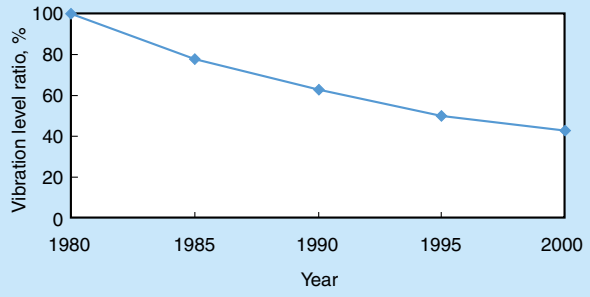

Fig. 1 Transition of vibration level of ball bearings for fan motors

processing technologies cannot completely eliminate waviness. To help minimize such irregularities, NSK has taken significant steps to improve the internal design of bearings. Examples of such achievements are shared in another report titled "Development of NSK's Extremely Quiet, Low-Torque, GR Series Ball Bearings" in this issue of Motion & Control.

2.2 Reduction of Other Sounds and Vibration

As greater reductions are made in race noise, which is the fundamental sound of a bearing as stated above, the other sounds of a bearing become audible. Naturally, our effort has also been focused on the reduction of these noises and vibration as well as the race noise of bearings. The following subsections describe some of the achievements we have made in this area.

2.2.1 Reduction of flaw noise

If any part of the rolling contact surface of the rolling elements of a bearing is scratched, dented, or otherwise sustains a shock, a harsh noise (flaw noise) can result having a waveform such as that shown in Fig. 2. Improper handling of the bearing is the main cause of such flaw noise. In response, bearing design and materials are developed to provide greater resistance to such shock loads, thus resulting in less flaw noise.

NSA Grease was developed by NSK to provide better protection against fretting (wear corrosion or friction oxidation), which is caused by shocks or vibration during transportation. NSA Grease was actually developed for bearings where improper handling is highly probable.

2.2.2 Reduction of cage noise

Cage noise arises more often than before because an increasing number of bearings are used in high-speed or low-temperature conditions. Cage noise unavoidably occurs whether the cage is a pressed, machined, or a plastic cage. Cage noise is not one sound, but can have a variety of sounds. Cage noise may resemble a chattering or rattling sound, as if hitting something, or at other times, it may have a rustling or rubbing sound. The mechanism of each sound is different from the other.

Basically, however, cage noise is caused by excessive runout, irregular movement, or cage whirl. Hence, narrowing the range of cage riding clearance is effective in reducing cage noise. Then again, excessively restricting cage movement can increase rotating torque and cause poor lubrication. For these reasons, provisions are often made to minimize cage noise, depending on the type of cage and particular bearing operating conditions, while also taking into consideration bearing performance factors.

2.2.3 Reduction of bearing noise in cold environments

Axial vibration (accompanied by noise) of bearings may occur when bearings are operated at very low temperatures (about -20°C to -40°C). This bearing noise can occur in grease-lubricated ball bearings and can usually be prevented by preloading the bearings.

In some bearing applications, however, bearing preloading is impracticable. The only solution to this type of noise is to redesign the bearing itself. In fact, bearing design to minimize noise is a standard practice, but there still are occasional cases where the noise cannot be satisfactorily reduced under very low-temperature operating conditions.

However, using NSK's specially developed grease and special internal structure design for noise control, bearings can operate free of noise even in very low-temperature environments.

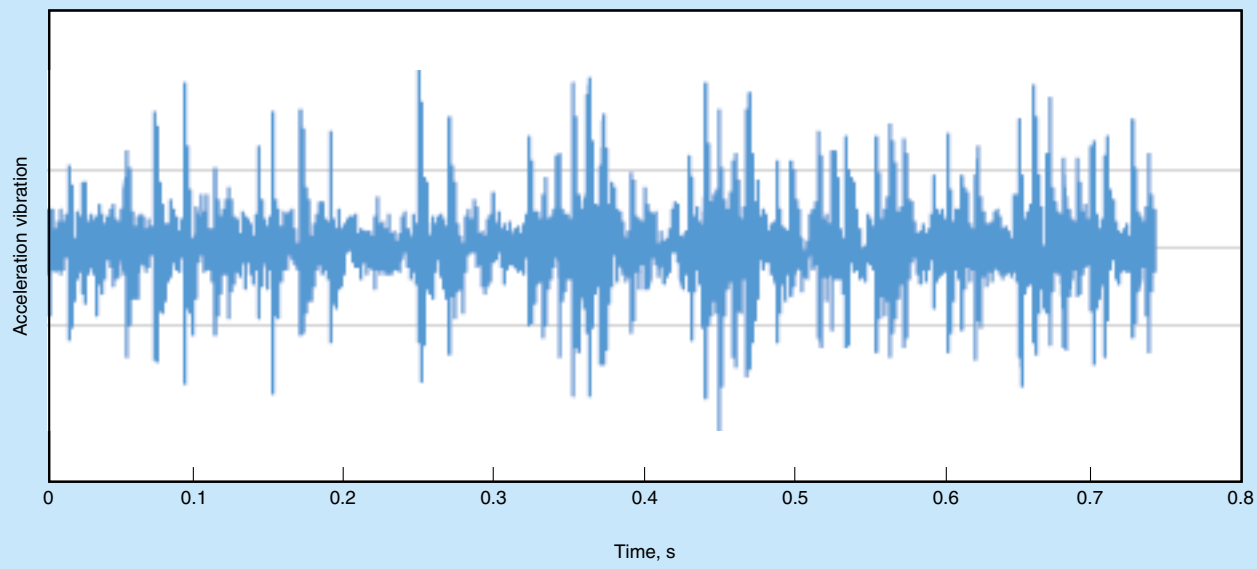

Fig. 2 Vibration waveform of flawed ball bearings

2.2.4 Reduction of squeal noise

The squeal noise of a bearing is a harsh metallic noise that tends to occur more often in relatively large grease-lubricated bearings. It can arise from ball bearings, but usually arises from cylindrical roller bearings. The noise can sometimes be very large, and requirements for its reduction are very demanding.

An effective means for controlling squeal noise is to reduce the radial clearance of the bearing. However, an excessively small clearance can cause seizure. Therefore, NSK developed cylindrical roller bearings that are free of any squeal noise and have no requirement for reducing radial clearance.

3. Reduction in Noise and Vibration of Ball Screws and Linear Guides

Ball screws and linear guides consist of a mechanism with return circulation path, which when operated, produce noise and vibration similar to the flaw noise occurring in rolling bearings. The levels of noise and vibration are greater as operation speeds become much higher. Demands for ball screws and linear guides with greater high-speed operating capability and increased performance with less noise and vibration are increasing. The NSK S1 Series™ ball screws and linear guides were developed to meet such demands. The S1 Series™ incorporates resin- retaining pieces interposed between steel balls to prevent ball-to-ball contact. The final result is a product with improved noise and vibration properties as well as improved operation and endurance performance.

3.1 Ball Screws

Fig. 3 compares the noise characteristics of a conventional type ball screw and an S1 Series™ ball screw having a shaft diameter of 40 mm and a lead of 10 mm. From this figure we can see that the S1 Series™ produces less noise throughout the entire range of shaft running speeds, and that it is particularly quiet when shaft running speed is low. Moreover, in terms of noise quality, the conventional ball screw produced a rather harsh noise, which is caused by the direct contact of the steel balls. The S1 Series™ however, eliminates such noise as the retaining pieces do not allow steel balls to collide with each other. In comparing the results based on actual listening, the S1 Series™ seemed to be much quieter than the measured noise level results[3].

The diameter and pitch circle diameter of steel balls and running speed are dominant factors affecting the noise levels of ball screws[4]. By taking advantage of this knowledge, and utilizing it in the design of ball screws, we can reduce noise levels. More specifically, NSK's design uses a larger lead and a lower running speed, or a smaller ball diameter and a smaller shaft diameter. However, consideration still needs to be given to the subsequent reduction in load carrying capacity.

3.2 Linear Guides

Fig. 4 compares the noise characteristics of a conventional linear guide LH30 and an S1 Series™ SH30 linear guide of the same size. From this figure we can see that the noise level of the S1 Series™ is lower by about 5 dB than that of the conventional linear guide. The S1 Series™ linear guide not only has retaining pieces between its steel balls, but also the circulation path, including the steel ball scoop section are improved. Results further show that the retaining pieces help achieve low noise levels when the feed rate is low, and that the improved circulation path design helps achieve low noise levels when the feed rate is higher[3].

In addition, like the S1 Series™ ball screw, the S1 Series™ linear guide has a greater quietness than conventional linear guides in the high-frequency range, which subsequently leads to better quality in noise.

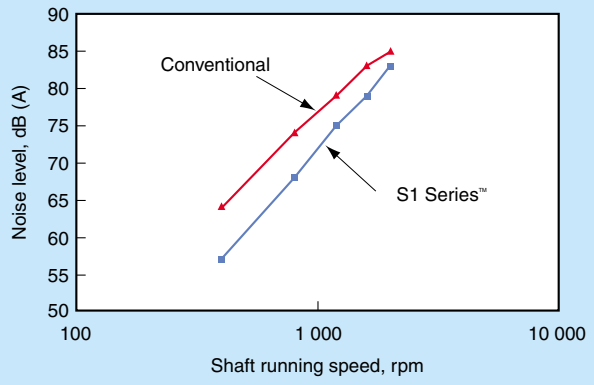

Fig. 3 Comparison of noise characteristics of ball screws

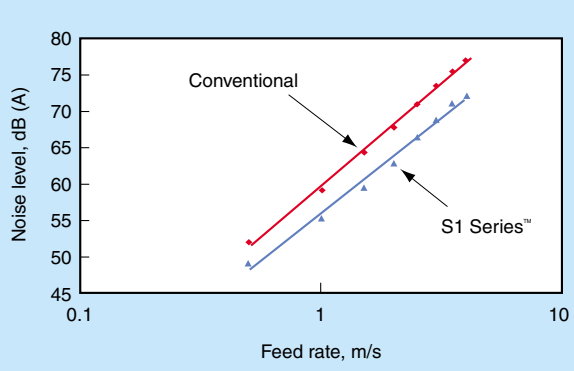

Fig. 4 Comparison of noise characteristics of linear guides

4. Conclusion

The foregoing sections have outlined a few of the approaches NSK has taken to reduce noise and vibration of rolling bearings and precision machine parts. The noise and vibration performance of these products is not only required for their initial service, but also required throughout their entire service life. Our technologies for enhancing noise and vibration performance life have produced many positive results, which are not reported here due to lack of space in this present issue of Motion & Control. We hope to be able to expand on other achievements in later issues.

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Banda Noda

Hub Unit Bearings with Multi-Pole Magnetic Encoders

1. Contribution to the Environment

Automotive components are required to be smaller and more lightweight in order to improve the fuel economy of automobiles. NSK thus developed and applied a multi-pole magnetic encoder to hub unit bearings. Our encoder is smaller and 85% more lightweight than conventional sensors and sensor rotors, which are used to detect the wheel rotation speed of antilock brake system (ABS) (Photo 1).

2. Features and Technical Points

The multi-pole magnetic encoder is a sensor rotor with an annular magnet that has been magnetized with multiple poles. The next-generation ABS uses this type of encoder (instead of a conventional magnetic sensor rotor), to detect the wheel rotation speed with a semiconductor magnetic sensor fixed to the car body (Fig. 1).

(1) Small and lightweight

The multi-pole encoder can be easily integrated with the seal, enabling downsizing and weight reduction through reduction of a number of parts. The encoder itself is extremely lightweight because of the use of magnetic rubber as opposed to conventional sensor rotors that use sintered metal or machined types. The use of magnetic rubber also eliminates the use of an actual magnet, which further promotes a smaller size and greater reductions in weight.

(2) Higher performance

The use of a semiconductor sensor frees the sensor output voltage from being dependent on the rotation speed of the multi-pole magnetic encoder, ensuring stability even at extremely low speed.

(3) Easy installation

As this encoder is incorporated into the bearing unit, assembly of the sensor rotor, which was traditionally done on the assembly line of the automobile manufacturer, becomes unnecessary.

(4) Various configurations

This encoder may be classified as a radial-type encoder in which the sensor is approached in a radial direction or as an axial type in which the sensor is approached in an axial direction. In addition to easy integration with the seal, the encoder itself can be installed independently of the bearing. This way, the multi-pole magnetic encoder can meet various configuration requirements.

3. Applications

- Detection of wheel rotation speed

Photo 1 Hub unit bearings with multi-pole magnetic encoders

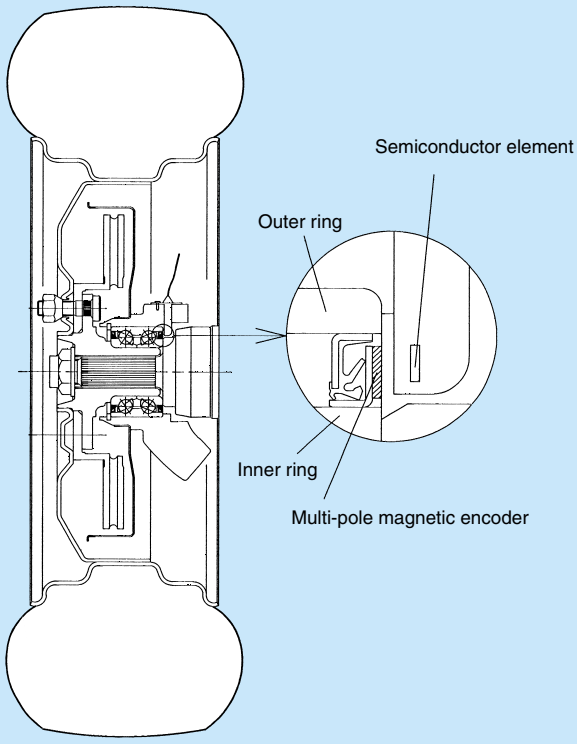


Fig. 1 Sample of structure for a multi-pole magnetic encoder

Double Roller for Diesel Engine Tappets

1. Contribution to the Environment

In view of recent environmental issues in Europe, demand for diesel engines with improved performance and fuel economy is growing. In some diesel engines, valves are actuated by means of a cam (tappet) roller to reduce frictional loss of power of the drive valve system.

In order to assure longer engine oil life, NSK has developed a highly durable double roller (Photo 1) that reduces tappet roller wear by 90% or slightly more (Fig. 1) and reduces running torque by 50% or slightly more when compared to a sliding tappet (Fig. 2).

Photo 1 Highly durable double roller

2. Features and Technical Points

(1) Steel shaft employment

The double roller employs a steel shaft, which consumes less energy during machining, and requires less machining time in comparison to a copper alloy shaft used in conventional single rollers. In addition, the amount of wear is substantially smaller than that of a copper alloy shaft. This in turn results in fewer impurities mixed into the engine oil, contributing to longer engine oil life (Fig. 1).

(2) Double roller employment

For a conventional roller follower under high contact pressure, insoluble contaminants mixed in the engine oil cause internal wear of the bearing. Normally, this problem is solved through the use of a single roller. However, at NSK, we have applied various technologies to create a double roller, which includes both inner and outer rollers. Consequently, slide surface area of the bearing exceeds that of a conventional single roller. Therefore, the friction coefficient of sliding surfaces is reduced, contributing to further reduction of wear of the shaft.

3. Applications

- Tappets for automotive diesel engines
- Fuel injection pumps for automobiles

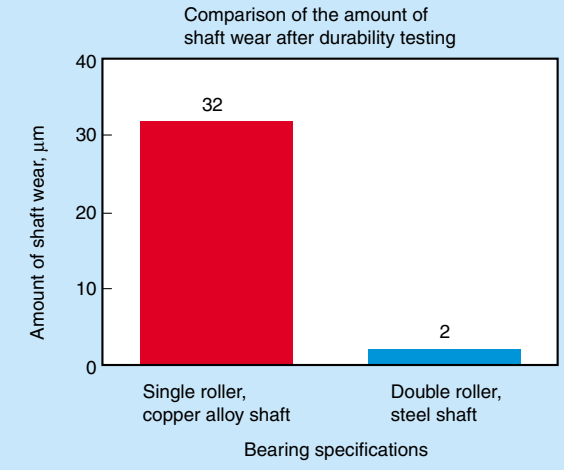


Fig. 1 Shaft wear by bearing types

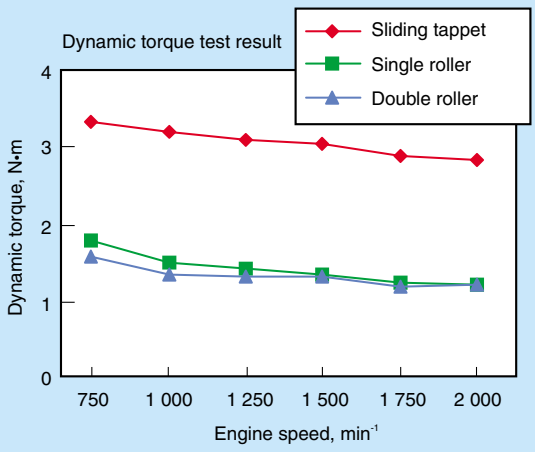


Fig. 2 Bearing torque by engine tappets

Thin Section Drawn Cup Needle Roller Bearings

1. Contribution to the Environment

NSK's thin section drawn-cup needle roller bearings (Photo 1) can be utilized in the same narrow space where plain bearings are conventionally used. Our drawn-cup type bearing utilizes a resin cage making it lightweight, with a maximum 75% reduction in torque when compared with plain bearings. This helps to improve fuel economy.

Plain bearings containing lead (Pb), which has a negative impact on the environment, can be replaced with our drawn-cup type bearings, enabling a substantial contribution to maintaining a cleaner environment.

This product is an effective substitute for plain bearings containing lead (Pb).

2. Features and Technical Points

(1) Same cross-section thickness as a plain bearing is achieved.

Through exploitation of NSK's machining technologies, the same sectional height of a plain bearing has been achieved. This product is used in the same narrow space where only plain bearings could have been used. (Fig. 1).

(2) Torque reduction through rolling

The torque ratio for a thin section drawn-cup needle roller bearing is about 25 to 75% when compared with a conventional plain bearing. The effect of reduced torque is higher particularly in the low speed range where fuel economy is worse (Fig. 2).

(3) Lightweight through the use of a resin cage

The use of a resin cage has succeeded in reducing drawn-cup type bearing weight by about 30%, contributing to reduced torque and increased speed.

(4) No damage on the environment

3. Applications

- Automotive transmission

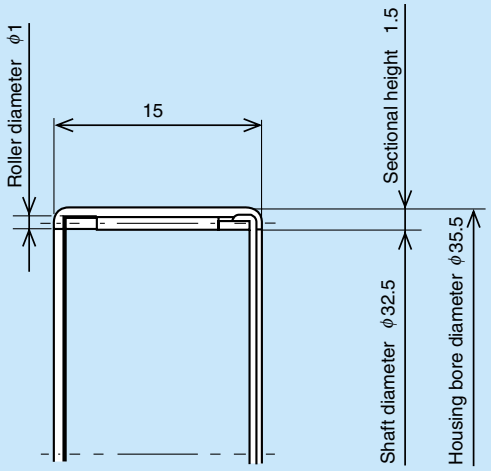


Fig. 1 Sectional view of bearing example

Photo 1 Thin section drawn-cup needle roller bearing

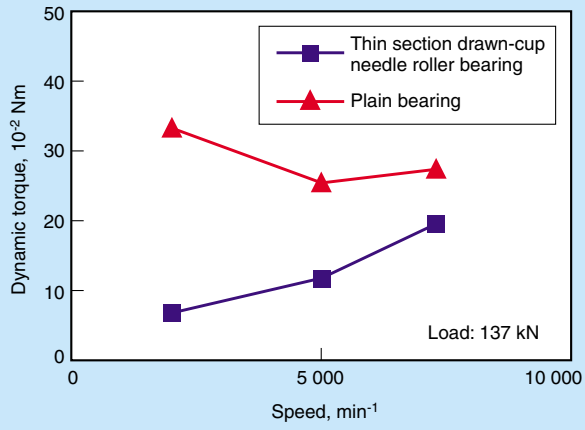


Fig. 2 Comparison of dynamic torque example

Low Frictional Torque Tapered Roller Bearings

1. Contribution to the Environment

Automotive transmissions and final reduction gears require that tapered roller bearings have reduced torque during rotation in order to improve fuel economy. NSK has developed tapered roller bearings (Fig. 2) comprising of a combination of two tapered roller bearings, which reduce rolling friction torque by about 20 to 40% compared to conventional products (Fig. 1).

2. Features and Technical Points

(1) First-generation low-torque tapered roller bearings
Internal technical data of this type of bearing, such as the inner ring large rib coarseness, roller head roughness, roller head geometry, and raceway crowning shape, have been optimized along with machining technology. Consequently, frictional torque was reduced by about 20% compared with the conventional products (Fig. 3).

(2) Second-generation low-torque tapered roller bearings
The frictional torque of tapered roller bearings can be approximated as follows:

$$T \doteqdot T_R + T_S$$

(T_R: Viscous resistance of EHL oil film, T_S: Friction of metal contact)

NSK made a detailed assessment of the factors of this equation after analyzing the frictional torque generated in tapered roller bearings. This has enabled forecasting of the frictional torque under practical operating conditions. The second-generation product is based on a design that has improved internal data without reducing life and rigidity as a two-bearing combination, while taking operating conditions into account, such as external load and speed. Our second-generation product has also optimized the roller diameter, number of rollers, roller length, and contact angle for the two-bearing combination in addition to all the features of the first-generation product. Namely, NSK's second-generation tapered roller bearings reduce frictional torque by about 20% compared with that of first-generation products (Figs. 3 and 4).

3. Applications

- Tapered roller bearings for automotive transmission
- Tapered roller bearings for automotive differential gears
- Tapered roller bearings for other applications

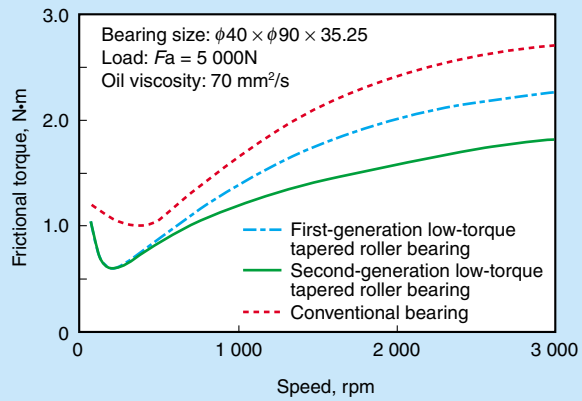


Fig. 3 Torque comparison between current bearings and low-friction bearings

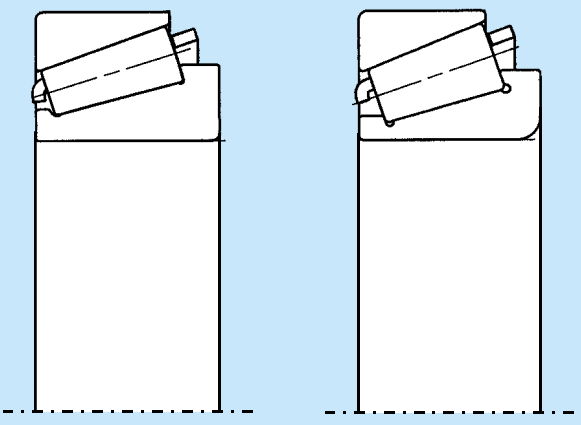


Fig. 1 Section of conventional design

Fig. 2 Section of new design

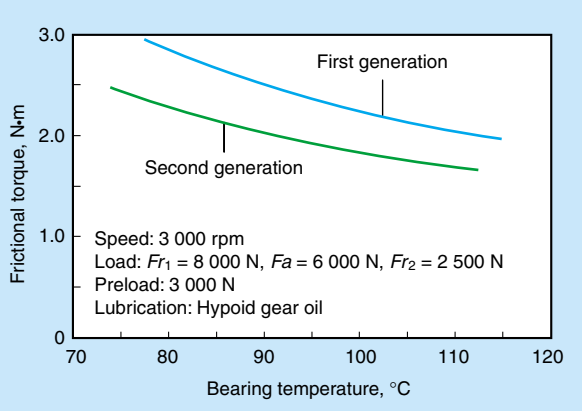


Fig. 4 Torque comparison for both generations of bearings

Sealed-Clean Bearings

1. Contribution to the Environment

The center distance (between drive and driven shafts) must be shortened in order to decrease the size and weight of an automobile transmission. However, reduction of the bearings outside diameter for this purpose causes a decrease in the bearing load rating, thus resulting in shorter life. Conversely, such a decrease in the bearing life is not acceptable if the demand put on engine output and transmission durability is increased.
NSK's sealed-clean bearing (Photo 1) can meet both differing requirements of a smaller bearing size (load rating) and longer life, allowing for a smaller and lighter transmission.

Photo 1 Sealed-clean bearings

2. Features and Technical Points

Transmission lubricating oil contains foreign matter, such as worn powder of gears and others. Such inclusions cause dents in the bearing raceway from which flaking develops. Our sealed-clean bearing has a seal (Fig. 1) developed specifically for transmissions that prevents entry of foreign matter into the bearing while allowing passage of the lubricating oil, which is necessary for the bearing. The life of this type of bearing under contaminated conditions is substantially longer than a standard bearing (open type bearing) (See Table 1.). An NSK sealed-clean bearing can have bearing size reduced while offering longer life.

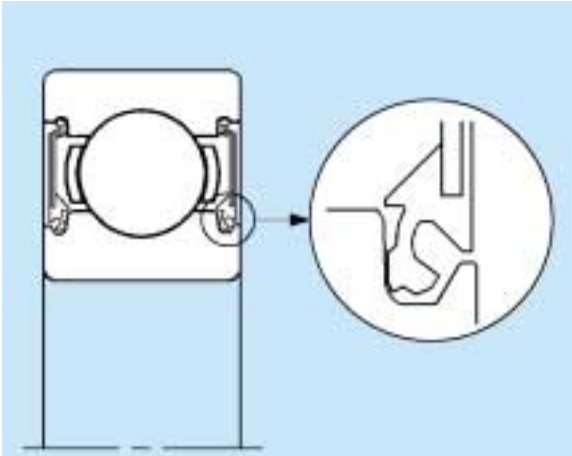


Fig. 1 Section of a sealed-clean bearing

3. Applications

- Automobile transmission

Table 1 Comparison of standard and sealed-clean bearings

Bearing type	Open type bearing	Sealed-clean bearing	
Bearing No.	6306	TM306	TM206
Bore diameter × outside diameter × width (mm)	ϕ30×ϕ72×19	ϕ30×ϕ72×19	ϕ30×ϕ62×16
Basic dynamic load rating	26 700 N	26 700 N	19 500 N
Life ratio based on results from an actual automobile transmission durability test	1	7 or more	4 or more
Product weight ratio	1	1	0.57

Lightweight TKZ, TRZ Clutch Release Bearing

1. Contribution to the Environment

Apart from the need to develop an environmentally friendly automobile with satisfactory fuel economy, there is a demand to manufacture automotive components that are more lightweight and can be manufactured with fewer resources. In response to such a demand, NSK has developed TKZ-type and TRZ-type clutch release bearings. These bearings have had their weight reduced by 30 to 40%, by substantially reducing the number of parts compared to conventional clutch release bearings.

2. Features and Technical Points

As shown in Table 1, the TKZ-type clutch release bearing employs the most simple two-piece clinch spring for its centering mechanism. The self-centering performance is therefore equivalent to that of a conventional wave-type spring (TKB type).

The bearing size has been reduced through optimum design and the use of a fine-contact seal, unique to NSK, has achieved a reduction of frictional torque.

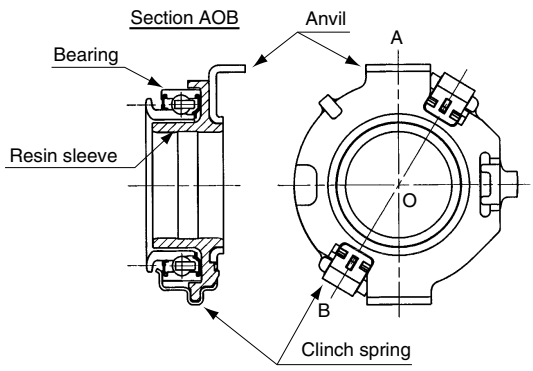
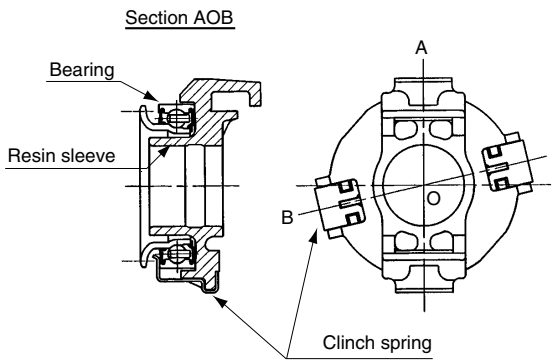
Moreover, a resin sleeve with flange is used, with the anvil connected by a clinch spring. As a result, the number of components has been reduced substantially from the conventional type, resulting in a lightweight product.

The TRZ-type has no steel-plate anvil with its function being provided by the resin sleeve. Accordingly, the number of components is minimal (three pieces), contributing to a substantial weight reduction.

3. Applications

- Clutch release bearing for a automobile manual transmission

Table 1 Characteristics of TKZ and TRZ clutch release bearings

	TKZ type	TRZ type
Appearance		
Construction		
Weight	30% lighter (as compared with NSK's conventional products)	40% lighter (as compared with NSK's conventional products)
Number of components	6 pieces (NSK's conventional products) → 4 pieces (TKZ)	6 pieces (NSK's conventional products) → 3 pieces (TRZ)

Highly Efficient and Lightweight Turbocharger Bearings

1. Contribution to the Environment

To improve fuel economy and reduce emissions, the significance of a turbocharger (Fig. 1) has increased, particularly for diesel engines.

NSK has developed rolling bearings (Fig. 2) for turbochargers that can help increase efficiency. These bearings reduce mechanical loss by about half of that of a turbocharger using conventional slide bearings, while reducing weight by about 10%.

2. Features and Technical Points

(1) Thermoplastic polyimide, a synthetic polymeric resin, was used for the cage.

Polyimide cages have higher heat and wear resistance, and greater strength than metallic cages. As a result, our turbocharger bearings are lighter, have less deterioration at high speeds and temperatures, and enjoy longer life.

(2) Ceramic balls for rolling element

Using ceramic balls with greater hardness and heat resistance for the rolling elements enable longer life at high temperatures and high speed, and ensure greater durability under contaminated operating conditions.

(3) Highly reliable, high-temperature steel (SHX) for inner and outer rings

The use of NSK-developed SHX, with high heat, wear, and seizure resistance, helps ensure high reliability.

3. Applications

- Supercharger, pressure-fed machine, and others.

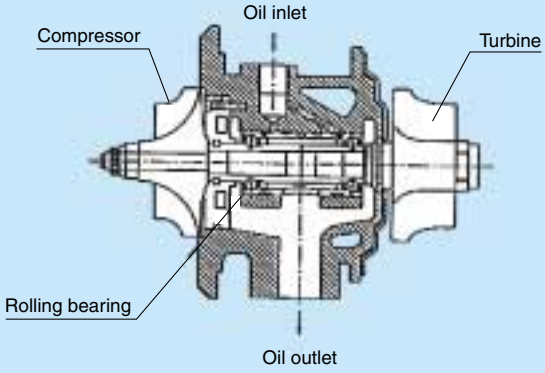


Fig. 1 Ball bearing type turbocharger

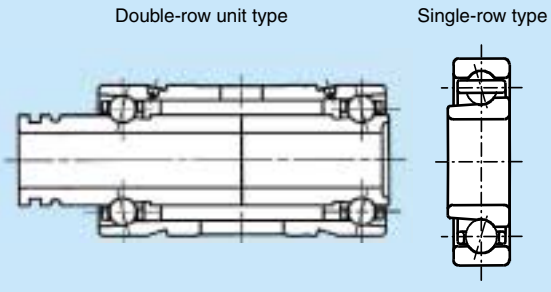
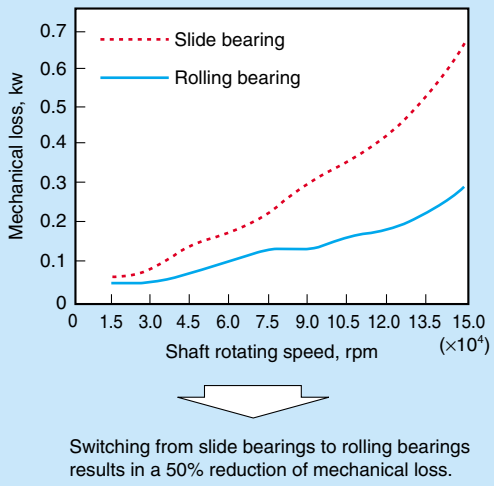


Fig. 2 Bearing types for turbochargers



Switching from slide bearings to rolling bearings results in a 50% reduction of mechanical loss.

Fig. 3 Comparison of mechanical loss

Thin Cross-Section Electromagnetic Clutch Bearings

1. Contribution to the Environment

Decreasing the weight and size of engine accessory equipment is required in order to enhance the fuel economy of automobiles. NSK has developed an electromagnetic clutch bearing with a minimal section height to meet speed, size and weight demands of the vehicle's air conditioning compressor. Our clutch bearing (Fig. 1) has achieved a 20% reduction in sectional height, a 6% reduction in outside diameter, and a 26% reduction in weight.

Photo 1 Electromagnetic clutch

2. Features and Technical Points

To increase rotation speed without decreasing compressor shaft rigidity, the outer ring outside diameter is reduced to suppress the pulley outside diameter without changing the bearing bore diameter.

To overcome concern that fatigue life of the bearing may significantly deteriorate, the following life extending measures are taken to ensure practical applicability (Fig. 2):

(1) NSK's EP steel (high cleanliness bearing steel) is used to prolong rolling fatigue life.

(2) Our newly developed MA grease is used to prevent premature flaking associated with structural changes that normally occur with bearings of engine accessory equipment.

3. Applications

- Pulley support bearing of an electromagnetic clutch (Photo 1) for a vehicle's air conditioning compressor.

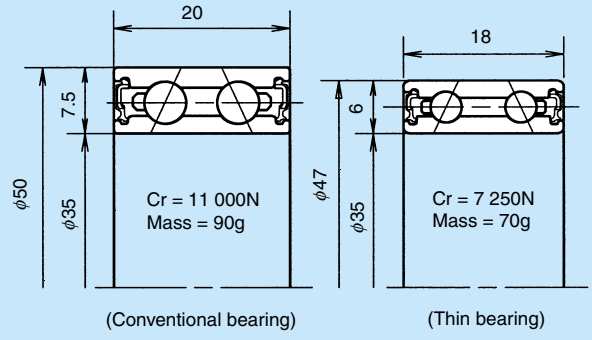


Fig. 1 Cross-section of an electromagnetic clutch bearing

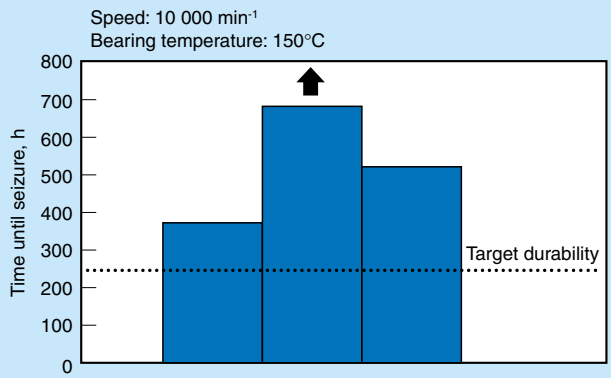


Fig. 2 Results of endurance test

Half-Toroidal CVT POWERTOROS Unit

1. Contribution to the Environment

Automobiles must have satisfactory fuel economy and reduced vehicle emissions. In response to such demands, NSK developed the half-toroidal CVT POWERTOROS Unit (Photo 1). This product contributes to the environment while offering a quick, smooth and continuous speed change that has never been experienced in automotive history.

2. Features and Technical Points

(1) POWERTOROS Unit

Based on NSK's extremely advanced tribology and precision processing technologies, we have produced the CVT for installation in cars with engine displacements of three liters or more for the first time in the world. Additionally, this unit can be applied to both large and small vehicles, offering smooth and powerful running with stepless speed changes (as is the case with conventional automatic transmissions).

The POWERTOROS Unit consists of input and output disks, and power rollers placed between both disks. Variation in the angle of the power rollers (Photo 2) determines the ratio of speed change. Shear force of the elastohydrodynamic lubrication (EHL) oil film, which exists between the disks and power rollers, enables transmission of power, thus ensuring smooth and highly efficient transmission of power.

This unit allows for the selection of any gear ratio through continuous (stepless) change of rotational speed, allowing the engine to constantly operate at optimum fuel economy. Engines integrated with the POWERTOROS Unit show a 10% or greater improved fuel economy in comparison to conventional automatic transmissions.

Photo 1 POWERTOROS Unit

(2) Power-split system

The half-toroidal CVT has transmission efficiency as high as 90 to 92%. To meet the demand for more efficient CVTs, a power-split system (Photo 3), which utilizes a differential gear unit by combining a half-toroidal CVT and a planetary gear, is being brought about for the second generation of the half-toroidal CVT. The system theoretically makes possible a transmission efficiency of 97% at maximum speed. Practical application of the POWERTOROS Unit makes the power split system suitable for practical use, which is expected to contribute to even better fuel economy.

3. Applications

- Automobile transmissions
- Change-speed gearboxes for various industrial machinery and equipment

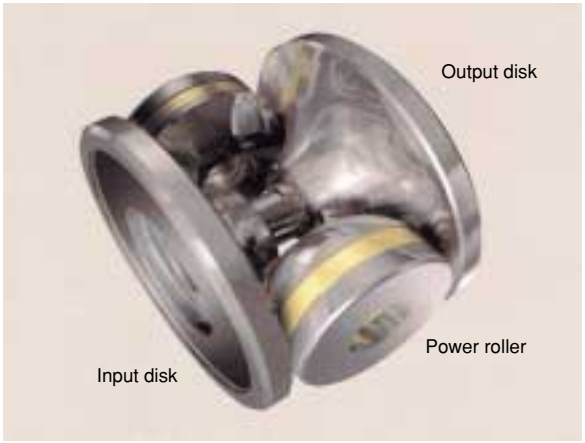


Photo 2 Basic structure of the half-toroidal CVT

Photo 3 Power-split system

NSK Linear Guides & Ball Screws Equipped with NSK K1® Lubrication Unit

1. Contribution to the Environment

The MF Series NSK linear guides and ball screws (Photo 1) are equipped with the innovative NSK K1® lubrication units which have been recognized as a world first. Marketed by NSK Ltd., they have been widely accepted by users.

NSK K1® is made from a unique material that contains a large amount of lubricant oil. This is a compact lubrication unit that maintains a steady and adequate supply of oil to the rolling surface and the surrounding area over a long period of time.

MF series became commercially available in the early part of 1996, and, since then, the users have been expressing greater interest on features of maintenance-free operations, greater cost savings, as well as environmentally sound products. In 1997, this technology was applied to high-load application, such as machine tools. In addition to enabling maintenance-free operation, this product contributes to the improvement of several environmental issues, such as decomposition and offensive odor occurring as a result of coolant and lubricant oil mixing, and waste oil disposal. Field results of this product are shown in Table 1.

2. Features and Technical Points

(1) Long-term maintenance-free operation

Together with the use of grease, this product provides sufficient lubrication for mechanical equipment operating under harsh conditions where there are complications related to lubricant supply.

(2) No contamination of oil into the environment

NSK K1® and a small amount of grease can ensure sufficient lubrication with enhanced cleanliness in places where oil contamination must be avoided, or in an environment where equipment requires a high level of cleanliness.

(3) Excellent performance in a water-contaminated environment

The use of NSK K1® with grease ensures longer life, even in environments where water splash or cooling oil may wash away the lubricant.

(4) Excellent performance in a dust-contaminated environment

The use of NSK K1® with grease ensures proper and sufficient lubrication and prevents entry of foreign matter over a long period, even in environments where the lubricant grease or oil is absorbed by surrounding dust.

3. Applications

- Machine tools
- Automobile manufacturing equipment
- LCD and semiconductor manufacturing equipment
- Food processing equipment
- Medical equipment
- Robotic equipment
- Woodworking machines, housing and construction machinery

Photo 1 MF series NSK linear guides & ball screws

Table 1 Field results

Purpose	Comparison of deterioration of linear guide with no K1 and with K1	
Sample	Linear guides (LH 30) for a welding machine on an automobile manufacturing line	
Specification	No NSK K1	With NSK K1
Operation period	10.5 months	13 months
Appearance	Heavy deterioration of balls and grooves with rusting	Much less deterioration of balls and grooves with no rusting
Clearance	About 7 μm clearance	Preload remaining, and no clearance
Rail groove condition		
Ball condition		

NSK S1 Series™ NSK Linear Guides and Ball Screws

1. Contribution to the Environment

In recent years, along with the performance enhancement of the machines in feeding speeds and functions, a growing demand has been placed on low vibration and low noise for improved working environment and safety. In addition, smoother operation of machinery is required.

NSK S1 Series™ ball screws and linear guides (Photos 1 and 2) have achieved noise reduction and smooth operation by incorporation of a resin retaining piece, and improvement of the internal design specifications.

2. Features and Technical Points

(1) Insertion of the retaining piece prevents jingles caused by the collision of steel balls at low-speed operation. The steel ball scooping section, connecting load and no-load zones, has been improved to alleviate collision of steel balls and other parts, which account for most of the high-frequency noise components during high-speed operation. As a result, the S1 Series has achieved improvements in noise level and noise tone in all speed ranges compared with existing products (Figs. 1 and 2).

(2) Freedom from jams among balls, improved scooping section and a better internal circulation circuit (no-load zone) have resulted in improvement of torque and friction characteristics (spikes and jamming). Especially at low speeds and during oscillation, energy conservation can be expected.

(3) When compared with a ball screw incorporating spacer balls, which has been used for greater smoothness, an S1 Series ball screw has more load-carrying steel balls. This allows the S1 Series to have a higher load rating and greater rigidity. This also enables more compact designs of ball screws while maintaining equivalent operability of a spacer-ball type screw.

(4) Interchangeable with existing products in dimensions.

3. Applications

- Applications sensitive to noise and vibration: measuring instruments, pattern generating systems, medical equipment, and office equipment.
- Applications requiring smooth operation: wire discharge machines, scanners, pattern generating systems, and steppers.

Photo 1 NSK S1 Series™ ball screw

Photo 2 NSK S1 Series™ linear guide

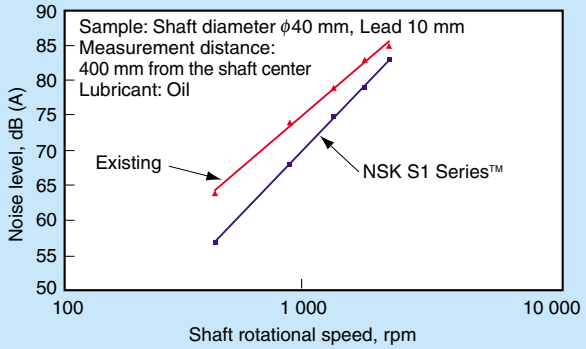


Fig. 1 Comparison of noise level of ball screws

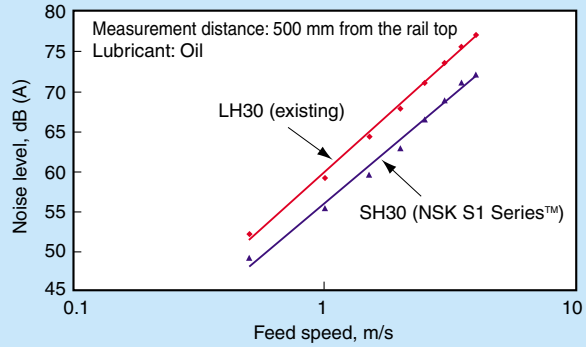


Fig. 2 Comparison of noise level of linear guides

Biodegradable EXCELLA GREEN™ Grease

1. Contribution to the Environment

Grease used for lubrication of rolling bearings and ball screws may contaminate the soil, rivers, or sea if it leaks or is disposed of improperly. This could inflict considerable harm on both the natural environment and the people that are living and working in the afflicted areas.

EXCELLA GREEN™ grease is readily decomposed by bacteria and contains no harmful substances. This biodegradable grease is eco-friendly, and has been certified as an environmental protection product by the Eco Mark Office of the Japan Environmental Association (JEA). Products certificated the Eco Mark have met specific criteria under the "Law on promoting the purchase of environmentally friendly products by the government and other public bodies" (Green Purchasing Law), which stipulates the systematic purchasing of environmentally friendly products by the national and local authorities (Effective April 1, 2001).

2. Features and Technical Points

EXCELLA GREEN™ NS7 grease (Photo 1) was developed by NSK in 1975, and is used in about 350 million NSK bearings a year. This long-life grease, for bearings in small- to medium-sized general purpose motors, air conditioner fan motors, and IT devices, has been in use for over 25 years with successful results.

EXCELLA GREEN™ NS7 grease is 60% or more biodegradable as determined by a 28-day biological oxygen demand test in bacteria-activated sludge, which is an effect evaluation index for an ecosystem. The environmental load of this grease is extremely small: acute toxicity of Oryzias latipes (killifish) is 100 mg/l or more in terms of the 96-hour LC_{50} value*.

EXCELLA GREEN™ grease is based on basic synthetic ester oil (superior oxidation, thermal stability, and lubricating qualities) while using lithium soap (superior heat and water resistance, mechanical stability, and provides a thickening function) (Table 1). Accordingly, this product can be used over a wide temperature range from -40°C to 130°C, ensuring longer grease seizure life to about twice or more of mineral oil type universal greases (Fig. 1).

* LC_{50} value: 50% lethal concentration. A lower value indicates higher toxicity.

3. Applications

- Machine elements in which grease leakage may cause contamination of surrounding environment
- Linear motion systems, such as NSK linear guides and ball screws used for high transient area control table (TACT) transport positioning
- Rolling bearings that require low torque, silence, and long life, such as for small- to medium-sized universal motors.

Photo 1 EXCELLA GREEN™ NS7 grease

Table 1 Typical characteristics of EXCELLA GREEN™ Grease

	Excella Green™ NS7 Grease
Thickener	Lithium 12-hydroxystearate
Base oil	Synthetic ester oil
Kinetic viscosity of base oil, mm²/s@40°C	26
Worked penetration	250

Test Conditions
Bearing: 6305VV
(ϕ25 mm × ϕ62 mm × 17 mm, Non-contact type rubber seal)
Radial load: 98N
Speed: 3 000 min⁻¹ Bearing temperature: 120°C
Grease A: Lithium soap – mineral oil (130 mm²/s@40°C)
Grease B: Lithium soap – ester oil + mineral oil (15 mm²/s@40°C)

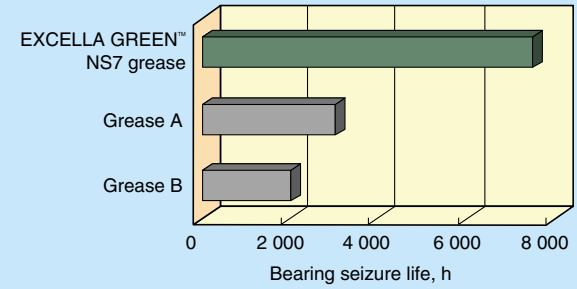


Fig. 1 Result of seizure life test

Electric Power Steering

1. Contribution to the environment

Currently, car manufacturers and their suppliers are paying more attention to environmentally related issues, such as improving fuel economy, reducing emissions, etc. New technologies or products that are environmentally friendly are receiving greater emphasis and attention. Naturally, NSK's electric power steering (EPS) system is counted among such products.

(1) Saving energy

Our EPS system consumes power only when the driver turns the steering wheel. 5% of the energy that a conventional hydraulic power steering system uses is all that is required for the EPS system. As a result, fuel consumption is 3 to 5% less for EPS-equipped vehicles. Therefore, EPS is regarded as an energy-saving power steering system.

(2) Environmentally friendly

Since hydraulic fluid is eliminated in the EPS system, there is no hydraulic fluid related environmental pollution at both the production and disposal stages of the vehicle and steering system.

2. Features and Technical points

Fig. 1 shows the construction of a pinion-type EPS.

Torque sensor: detects the driver's input torque of the steering wheel, as well as the movement of the vehicle.

Electronic control unit (ECU): performs turning force calculations based on signals from the torque sensor.

Motor: generates turning force according to output from the ECU.

Reduction gear: reduces the rotary speed of the motor and amplifies the turning force.

Vehicle and engine speed information are relayed to the ECU, which is then used for vehicle speed-reactive type EPS systems.

There are two types of EPS systems being mass-produced:

(1) A column type where the motor and reduction gear are mounted on the steering column, just below the steering wheel.

(2) A pinion type where the motor and reduction gear are mounted on the pinion of the rack and pinion assembly.

3. Applications

NSK predicts that the need for EPS systems will increase due to its ability to improve fuel consumption, adaptability to hybrid vehicles and ability to control all the necessary functions electronically.

As a leading manufacturer of EPS, NSK is undertaking development to further improve lightweight, high-functionality, strong performance and high output systems to meet increasing customer requirements.

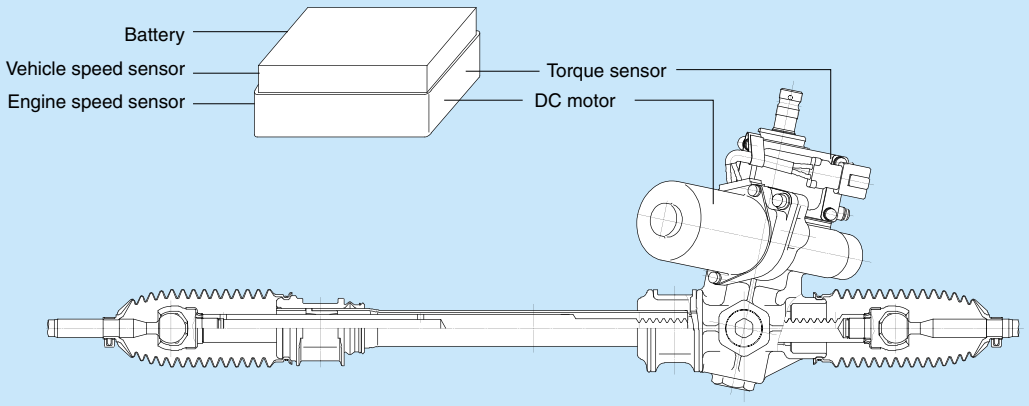


Fig. 1 Construction of a pinion type EPS assembly

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