

*NSK Technical Journal*

# Motion & Control

## No. 7

December 1999



**NSK**

*MOTION & CONTROL No. 7*

*NSK Technical Journal*

*Printed and Published: December 1999*

*ISSN1342-3630*

*Publisher: NSK Ltd., Ohsaki, Shinagawa, Tokyo, JAPAN*

*Public Relations Department*

*TEL +81-3-3779-7051*

*FAX +81-3-3779-7431*

*Editor: Kyozauro FURUMURA*

*Managing Editor: Yasuhiko MORITA*

*Design, Typesetting & Printing: Fuji Ad. Systems Corp.*

*Cover photos: NSK Headquarters, NSK Ltd. (Japan)*

*NSK Safety Technology (Thailand)*

*Maebashi Plant, NSK Ltd. (Japan)*

*© by NSK Ltd.*

*The contents of this journal are the copyright of NSK Ltd.*

# Motion & Control

## No. 7

December 1999

---

## Contents

<b>SPACEA™ Series Products for Special Environments</b> .....	<b>1</b>
<b>Bearings for Traction Gears</b> .....	<b>9</b>
<b>Inner Ring Fracture Characteristics under Rolling Contact</b> .....	<b>15</b>
<b>ABS Motor/Actuator Bearing Development for Applications Which Require Brake Fluid Compatible Contact Seals</b> .....	<b>24</b>
<b>High-Performance Ball Bearings for Fan Motors in the Chinese Market</b> ----	<b>27</b>
 <b>New Products</b>	
<b>SNN Series Plummer Blocks</b> .....	<b>31</b>
<b>RMA and RMS Series of Precision Rolled Miniature Ball Screws</b> -----	<b>33</b>

# SPACEA™ Series Products for Special Environments

## I. SPACEA™ Series Bearings

*Shigeki Matsunaga*  
*Bearing Technology Center*

### 1. Introduction

For more than ten years, NSK has been designing advanced motion and control products to support the increasingly sophisticated needs of high-tech industry. We have developed unique material, lubrication and surface treatment technologies that provide solutions for extremely severe conditions. Our efforts in this area have culminated in the creation of the SPACEA Series, a range of bearings, ball screws and linear guides for special operating environments such as outer space; clean rooms for semiconductor, LCD panel and hard disk manufacturing; and environments where highly corrosive chemical solutions are present. This report presents the SPACEA Series Bearings.

### 2. Special environments

Special environments include:

- Clean environments  
Semiconductor, LCD panel and hard disk manufacturing equipment for which dust generation must be minimized
- Vacuum environments  
Vacuum equipment in which thin films are applied to components, space exploration equipment
- Corrosive environments  
Food processing machines where water exposure is high, film manufacturing equipment that uses corrosive solutions, hot dipping tanks for surface treatment of steel plate with melted zinc
- High-temperature environments  
Roller conveyors in heat treatment furnaces, kiln cars
- Nonmagnetic environments  
Semiconductor manufacturing equipment, medical diagnostic instruments
- Low-temperature environments  
Liquid gas-submerged pumps, liquid fuel turbo pumps
- Radioactive environments  
Nuclear and fusion reactors
- Environments contaminated with foreign particles  
Woodworking machinery, iron shops
- High-speed environments  
Machine tools, jet engines, turbochargers

### 3. Types of SPACEA Series Bearings

SPACEA Series Bearings consist of the four types shown in Table 1. Each component of all-ceramic bearings, including the outer and inner rings and rolling elements, is made of ceramics. With hybrid bearings, the rolling elements are made of ceramics while the outer and inner rings are made of metal. Coated bearings have all or part of their outer rings, inner rings and/or rolling elements coated with a solid lubricant such as gold, silver, Teflon or a corrosion-resistant material. Stainless steel bearings are generally lubricated with grease. The specifications of the various SPACEA Series Bearings are listed in Table 2.

### 4. New NSK Technologies Applied to SPACEA Series Bearings

#### 4.1 Technologies for minimizing particle emissions

##### 4.1.1 Clean-room grease

Bearings used in clean environments such as diffusion furnaces and steppers must not emit grease or wear particles. Fluorine grease has been used in the past, but it presents problems with its high torque, limited resistance to wear and rust, and high cost. In response, NSK applied its extensive knowledge of grease and, ahead of other bearing manufacturers, developed a clean-room grease that emits very few particles. NSK's bearings for clean environments, widely used in LCD panel and semiconductor manufacturing equipment, are lubricated with this grease.

##### 4.1.2 Special LDF fluoro-resin coating

Due to continued component integration and the larger size of LCD panels, the operating environment of bearings in sputtering and CVD (chemical vapor deposition) equipment is becoming more and more severe in terms of both temperature and degree of vacuum. For this reason, the method of lubrication in such applications is shifting from grease to solid lubricants, with fluoro-resin-coated bearings being widely promoted. The problem is that most fluoro-resin coatings are baked on using some kind of binder and therefore exhibit poor lubrication performance or emit high levels of particles under high temperatures and/or high loads. In response, NSK has developed a

special fluororesin coating called LDF that is applied through a special process without using a binder. The LDF coating is the optimum solid lubricant for either atmospheric or vacuum clean environments and it is used in LCD panel, semiconductor and hard disk manufacturing equipment.

## 4.2 Corrosion prevention technologies

### 4.2.1 Corrosion-resistant coatings

In wafer and hard disk cleaning machines, either corrosion-resistant ceramic bearings or bearings made of components coated with corrosion-resistant materials are used. Ceramic bearings have higher corrosion resistance but are more expensive. Common corrosion-resistant coatings have included electroless nickel and chrome among others, but these coatings cannot withstand exposure to hydrochloric, sulfuric or hydrofluoric acid. In response, NSK developed two new corrosion-resistant coatings: fluoride low-temperature chrome and nickel alloy. The fluoride low-temperature chrome is a low-cost coating for general use. The nickel alloy, while more expensive, provides higher corrosion resistance. These corrosion-resistant coatings have proven to be highly effective and are used in bearings for industrial cleaning machines where corrosive compounds are found.

### 4.2.2 Corrosion-resistant stainless steel

While AISI440C martensite stainless steel is more corrosion-resistant than bearing steel for normal environments, corrosion may still occur under various degrees of exposure to water or salt water. In consideration of this, NSK developed ES1 martensite stainless steel, which has higher corrosion resistance. This steel is most suitable for environments where rust must be prevented. Bearings made of this material are utilized in LCD panel, semiconductor and hard disk production machinery.

### 4.2.3 Highly corrosion-resistant ceramics

Silicon nitride bearings last about 10 times longer in water than stainless steel bearings. However, in etching and cleaning machines, where highly corrosive chemical

solutions are used, even silicon nitride ceramic bearings can fail prematurely as a result of the dissolution of their binder by the corrosive agent. In response, NSK developed highly corrosion-resistant carbide-based and oxide-based ceramics. Carbide-based ceramic bearings have longer life than other ceramic bearings in corrosive solutions and are therefore used in etching machines and cleaning machines where highly corrosive agents are used. Oxide-based ceramic bearings are low cost and have longer life in water than carbide-based ceramic bearings. They are widely used in rinsing machines.

## 4.3 Lubricant development technology: Molded-Oil™ Bearings

Molded-Oil Bearings were developed by applying the technology behind NSK K1 lubrication units for linear guides and ball screws. Developed by NSK, Molded-Oil is a solid compound consisting of polyolefin resin and at least 50% lubricating oil. In environments where conventional lubrication methods are not feasible (e.g., environments in which bearings are exposed to water and/or dust particles), Molded-Oil extends maintenance intervals and keeps machinery clean as only a small amount provides adequate lubrication.

## 4.4 Nonmagnetic stainless steel

Beryllium copper alloys and ceramics have been used in the past as nonmagnetic material for magnetic environments. However, these materials have significant drawbacks: beryllium copper alloys have low hardness and ceramics are expensive. To overcome these problems, NSK developed nonmagnetic stainless steel bearings. These bearings are used in semiconductor production machinery and medical diagnostic instruments.

## 4.5 Evaluation technology

Bearings for special environments are used in various applications, and bearing performance needs to be evaluated under test conditions that as closely as possible simulate actual operating conditions. Some examples of NSK's evaluation technologies include: X-ray tube bearing testers for vacuum applications, aerospace equipment

Table 1 SPACEA Series Bearings

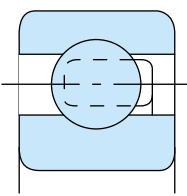
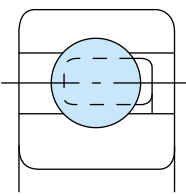
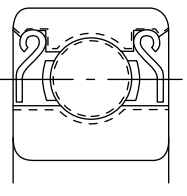
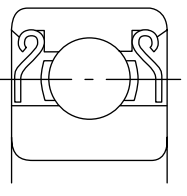
				
	All-ceramic bearings	Hybrid bearings	Coated bearings	Grease packed stainless steel bearings
Outer/inner rings	Ceramics	Bearing steel or stainless steel	Stainless steel	Stainless steel
Rolling elements	Ceramics	Ceramics	Stainless steel	Stainless steel
Coating or lubrication	None or solid lubricant	Grease, oil or none	Fluororesin or other solid lubricant coating	Fluorine grease or clean-room grease
Cage	Fluororesin cage or composite material cage for high temperatures	Nylon resin cage or fluororesin cage	Fluororesin cage or composite material cage for high temperatures	Stainless steel cage or nylon resin cage

Table 2 Specifications of SPACEA Series Bearings

Environment	Operating conditions					Requirements	Bearing specifications			
	Temperature	Air	Vacuum	Corrosive conditions	Magnetic fields		Inner ring/Outer ring	Balls	Cages	Grease
Clean	Room temperature	○				Low dust	Martensite stainless steel	Martensite stainless steel	Austenite stainless steel or resin	Clean-room grease
		○	○						Austenite stainless steel	Fluorine grease
	Up to 200°C	○				Low dust, corrosion resistance, non-magnetism, insulation	Martensite stainless steel or ceramics	Martensite stainless steel or ceramics	Fluororesin	—
		○	○						Austenite stainless steel + special fluororesin coating	—
	Up to 250°C	○	○						High-temperature self-lubricating resin	—
Up to 300°C	○	○								
Vacuum	Room temperature		○			Lubricity		Martensite stainless steel	Austenite stainless steel	Fluorine grease
	Up to 300°C	○	○			Lubricity, heat resistance	Martensite stainless steel	Martensite stainless steel + molybdenum disulfide coating	Austenite stainless steel + molybdenum disulfide coating	—
				○					Martensite stainless steel + lead coating	Austenite stainless steel
	Up to 400°C			○					Martensite stainless steel + silver coating	
Corrosive	Room temperature	○		○		Corrosion resistance	Martensite stainless steel	Martensite stainless steel or ceramics	Austenite stainless steel or fluororesin	Waterproof grease
	Up to 200°C	○	○	○			Martensite stainless steel + corrosion-resistant coating	Martensite stainless steel + corrosion-resistant coating or ceramics	Fluororesin	—
		○	○	○			Precipitation-hardened stainless steel	Ceramics		—
		○	○	○	○		Ceramics			—
High temperature	Up to 400°C	○				Heat resistance	Martensite stainless steel	Martensite stainless steel or ceramics	Graphite-based self-lubricating material	—
	Up to 500°C	○					Ceramics	Ceramics		—
Nonmagnetic	Room temperature	○	○		○	Non-magnetism	Nonmagnetic materials	Ceramics	Austenite stainless steel or resin	Fluorine grease
	Up to 200°C	○	○	○	○		Ceramics		Fluororesin	—
Low temperature	Down to -270°C	○				Lubricity	Martensite stainless steel	Martensite stainless steel	Fluororesin	—
Radioactive	Up to 120°C	○				Radiation resistance	Bearing steel	Bearing steel	Cold-rolled steel	Radiation-resistant grease
High speed	Room temperature	○				High-speed tolerance	Bearing steel or martensite stainless steel	Ceramics	Resin	High-speed grease, oil-air or jet oiling

bearing testers, turbomolecular pump touch-down bearing test rigs, and tests rigs for particle emissions and out-gassing. NSK applies these and other methods to predict bearing life and measure particle emission, torque and other factors under actual operating conditions.

## 5. Specifications of SPACEA Series Bearings

The principal specifications and applications of SPACEA Series Bearings are listed in Tables 2 and 3. The following sections review bearings for specific environments.

### 5.1 Bearings for clean environments

Bearings for clean environments are divided into two groups: those lubricated with clean-room grease and those

Table 3 Applications of SPACEA Series Bearings

Environment	Major applications
Clean	Liquid crystal, semiconductor and hard disk mfg. equipment; food processing and medical equipment
Vacuum	Space equipment, vacuum equipment, stepping motors, vacuum deposition equipment, electronic device mfg. equipment, X-ray tubes, turbomolecular pumps
Corrosive	Liquid crystal, semiconductor and hard disk mfg. equipment; food processing, film mfg. and cleaning equipment; molten plating tanks
High temperature	Heat treatment furnace roller conveyors, kiln cars
Nonmagnetic	Semiconductor mfg. equipment, medical inspection equipment
Low temperature	Liquid fuel turbo-pumps, liquefied gas-submerged pumps
Radioactive	Nuclear reactors, nuclear fusion reactors, accelerators
High speed	Machine tools, jet engines, turbochargers

lubricated with fluoro-resin. In addition to emitting very few particles, ceramic bearings, which are usually lubricated with fluoro-resin, provide the additional benefits of corrosion resistance, nonmagnetism and insulating properties.

### 5.2 Bearings for vacuum conditions

For operation in vacuum environments where ambient temperatures are not high, bearings may be lubricated with a fluorine grease of low vapor pressure. In higher temperatures where fluorine grease may evaporate, it is necessary to use a solid lubricant. Bearings whose components are coated with silver, lead or molybdenum disulfide have been used in X-ray tubes, turbomolecular pumps, vacuum equipment and aerospace equipment for more than 10 years.

### 5.3 Corrosion-resistant bearings

Corrosion-resistant bearings include several types each of coated and ceramic bearings. The corrosion resistance and operating performance of corrosion-resistant bearings can vary depending on operating conditions, so care should be taken when selecting the best bearing for a specific application.

### 5.4 Bearings for high and low temperatures

Bearings for high temperatures employ a graphite-based lubricating material effective up to 500°C. They are made of stainless steel or ceramics depending on operating conditions. Bearings for low temperatures are lubricated with low-viscosity oil, and their cages are lubricated with fluoro-resin. They can be used without requiring maintenance over a long period.

### 5.5 Nonmagnetic and radiation-resistant bearings

Nonmagnetic bearings are made of either nonmagnetic stainless steel or ceramics and lubricated with grease or fluoro-resin.

Lubricant selection is the most important concern for radiation-resistant bearings. Standard grease is used for radiation up to 10<sup>6</sup> rad while radiation-resistant grease is used from 10<sup>6</sup> to 10<sup>9</sup> rad.

### 5.6 Molded-Oil™ Bearings for environments contaminated by water and foreign debris

Molded-Oil Bearings contain solidified oil instead of grease. As with NSK K1 lubrication units for precision machinery, maintenance intervals are extended thanks to the continuous supply of lubricating oil and the sealing action of molded oil. Molded-Oil deep groove ball bearings as well as roller bearings are available. The bearings are used in environments where water washes out grease (e.g., food processing machinery) and in environments contaminated by foreign debris (e.g., steel mill equipment).

### 5.7 Bearings for high speeds

Hybrid bearings, which have ceramic balls and steel rings, are used for high-speed applications. Compared to all-steel ball bearings, hybrid bearings have lower friction between their balls and raceways. Consequently, they have low temperature rise and can operate at higher speeds. For this reason, hybrid bearings are used in machine tool spindles. NSK's recently developed ROBUST Series for machine tool spindles includes hybrid bearings.

## 6. Conclusion

We have presented here the technologies behind SPACEA Series Bearings and briefly summarized the various types of bearings in the series. To keep pace with the increasing severity of bearing operating environments, the development and improvement of the SPACEA Series will continue.



Shigeki Matsunaga

# II. SPACEA™ Series Ball Screws and NSK Linear Guides

Toshiharu Kajita  
Precision Machinery & Parts Technology Center

## 1. Introduction

The basic technologies described in Part I have been adapted for use with ball screws and linear guides for special environments. The technologies can be broken down into two groups: lubrication technologies and material technologies (Fig. 1). Lubrication technologies include special greases, molded oil and solid lubricants; material technologies include corrosion-resistant coatings, special steels and ceramics. Table 1 lists the specifications of ball screws for special environments while Table 2 summarizes the specifications of linear guides. SPACEA Series Ball Screws and NSK Linear Guides are already widely used in various industries including semiconductor and LCD panel production machinery, equipment used in nuclear power generation, and actuators for controlling aircraft, rockets and satellite equipment.

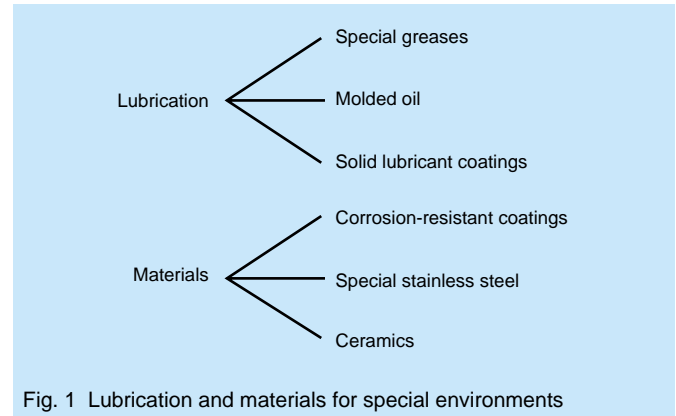


Fig. 1 Lubrication and materials for special environments

Table 1 Specifications of SPACEA Series Ball Screws

Environment	Operating conditions	Ball screw specifications			
		Shaft/Nut	Balls	Recirculation components	Lubricant/Surface treatment
Clean	Air, room temperature	Standard material	Standard material	Standard material	Clean-room grease LG2, NSK K1™
		Martensite stainless steel	Martensite stainless steel	Austenite stainless steel	Clean-room grease LG2, NSK K1™, fluoride low-temperature chrome coating
	Air/Vacuum, room temperature			Fluorine grease, solid lubricant	
	Air/Vacuum, up to 200°C			Fluorine grease	
Vacuum	Air/Vacuum, room temperature				Fluorine grease, solid lubricant
	Air/Vacuum, up to 200°C	Martensite stainless steel	Martensite stainless steel	Austenite stainless steel	Molybdenum disulfide
	Air/Vacuum, up to 300°C				Silver coating
	High vacuum, up to 500°C				
Corrosive	Acid, alkaline, clean	Standard material	Standard material	Austenite stainless steel	Fluoride low-temperature chrome coating
		Martensite stainless steel	Martensite stainless steel		Fluorine grease
		Precipitation-hardened stainless steel	Precipitation-hardened stainless steel		
	Strong acid, high alkaline, clean, nonmagnetic	Ceramics	Ceramics		
Nonmagnetic	Air/Vacuum, clean	Special austenite steel	Ceramics	Austenite stainless steel	Fluorine grease
	Air/Vacuum, up to 200°C, clean	Ceramics			Fluororesin
High temperature	Air, up to 200°C	Standard material	Standard material	Austenite stainless steel	Fluorine grease
	Air, up to 200°C, corrosive	Martensite stainless steel	Martensite stainless steel		Fluoride low-temperature chrome coating
	Air, up to 500°C, corrosive	Ceramics	Ceramics		Fluoride low-temperature chrome coating, fluoride grease
Low temperature	Down to -273°C	Martensite stainless steel	Martensite stainless steel	Austenite stainless steel	Solid lubricant
Radioactive	Air	Standard material	Standard material	Standard material	Radiation-resistant grease
		Martensite stainless steel	Martensite stainless steel	Austenite stainless steel	
Foreign particle contaminated	Dust, wood chips	Standard material	Standard material	Standard material	NSK K1™, grease
	Water	Martensite stainless steel	Martensite stainless steel	Austenite stainless steel	

## 2. Summary of SPACEA Series Ball Screws and NSK Linear Guides

### 2.1 Environments where dust particles and/or water are present

The most significant difference between ball screws and linear guides, and conventional rolling bearings is the unavoidable direct exposure of the screw shafts and linear guide rails to such detrimental factors as dust particles and water. Dust particles and water hinder the smooth rolling motion of balls and accelerate wear of the balls and grooves by impairing the effectiveness of lubrication. Left unchecked, these conditions can ultimately lead to breakage. Previously, it was difficult to maintain good performance under such conditions unless lubricating oil was constantly supplied by automatic lubricating devices. The unavoidable waste of lubricating oil that this involved was a problem not only in terms of its cost and maintenance headaches, but also in terms of its detrimental effect on the environment. In response, we created the NSK K1 lubrication unit—a groundbreaking product that eliminates lubricant waste while extending maintenance intervals (Photo 1). NSK K1 lubrication units are made of molded oil, a new synthetic

resin material developed by NSK. The material contains at least 50% lubricating oil that gradually oozes out over a long period of time. Using NSK K1 lubrication units in combination with grease replenishes oil removed from grease through exposure to water and dust particles.



Photo 1 Ball Screw and NSK Linear Guide with NSK K1™ lubrication unit

Table 2 Specifications of SPACEA Series NSK Linear Guides

Environment	Operating conditions	NSK Linear Guide specifications			
		Rail/Ball slides	Balls	Recirculation components	Lubricant/Surface treatment
Clean	Air, room temperature	Standard material	Standard material	Standard material	Clean-room grease LG2, NSK K1™
	Air/Vacuum, room temperature	Martensite stainless steel	Martensite stainless steel	Austenite stainless steel	Clean-room grease LG2, NSK K1™, fluoride low-temperature chrome coating
	Air/Vacuum, up to 200°C				Fluorine grease, solid lubricant
Vacuum	Air/Vacuum, room temperature	Martensite stainless steel	Martensite stainless steel	Austenite stainless steel	Fluorine grease, solid lubricant
	Air/Vacuum, up to 200°C				Molybdenum disulfide
	Air/Vacuum, up to 300°C				Silver coating
	High vacuum, up to 500°C				
Corrosive	Water vapor, water	Martensite stainless steel	Martensite stainless steel	Austenite stainless steel	Fluoride low-temperature chrome coating
	Acids, alkalis	Standard material	Standard material	Standard material	Fluoride low-temperature chrome coating
	Acids, alkalis, clean	Martensite stainless steel	Martensite stainless steel	Austenite stainless steel	Fluoride low-temperature chrome coating, clean-room grease LG2
	Strong acids, strong alkalis				Fluoride low-temperature chrome coating, fluorine grease
	Organic solvents				Fluorine grease
High temperature	Air, up to 150°C	Standard material	Standard material	Austenite stainless steel	ET 150 grease
	Air, up to 200°C	Martensite stainless steel	Martensite stainless steel		Fluorine grease
	Air, up to 200°C, corrosive				Fluoride low-temperature chrome coating, fluorine grease
Low temperature	Down to -273°C	Martensite stainless steel	Martensite stainless steel	Austenite stainless steel	Solid lubricant
Radioactive	Air	Standard material	Standard material	Standard material	Radiation-resistant grease
		Martensite stainless steel	Martensite stainless steel	Austenite stainless steel	
Foreign particle contaminated	Dust, wood chips	Standard material	Standard material	Standard material	NSK K1™, grease
		Martensite stainless steel	Martensite stainless steel	Austenite stainless steel	
	Standard material		Standard material	Standard material	
	Water		Martensite stainless steel	Austenite stainless steel	

## 2.2 Clean environments

Unlike applications in environments where dust particles and/or water are present, ball screws and linear guides for semiconductor and LCD panel production machinery must generate as few particles as possible. In the past, fluorine grease was used to achieve this, but its problems of high torque, limited resistance to wear and rust, and high cost made it a less than satisfactory option. A more effective alternative was therefore in strong demand. NSK responded ahead of its competitors by introducing LG2 clean-room grease. This grease overcame the problems of fluorine grease and was very well received by numerous manufacturers of semiconductor and LCD panel production machinery. Now we are supplying ball screws and linear guides with our new and improved LGU clean-room grease. The temperature range of LGU grease has been widened from the -20~70°C of LG2 to -30~120°C. Additionally, metal content has been extremely reduced. We believe that, as a result, this grease can be used in a wider range of applications.

## 2.3 Corrosive environments

Ball screws and linear guides for use in LCD panel and semiconductor production must be resistant to the corrosive chemicals used therein. As a result of repeated testing with various corrosive chemicals, NSK recommends ball screws and linear guides coated with low-temperature chromium fluoride plating for such applications. For still higher corrosion resistance, NSK is developing nickel alloy-coated ball screws and linear guides.

## 2.4 Vacuum conditions

In addition to positioning stages driven in vacuum environments, NSK's ball screws and linear guides are used in satellites, space station equipment and rocket engine jet nozzle control actuators. Lubrication is the biggest problem in vacuum environments. Generally, fluorine grease is recommended for vacuums, but if the degree of vacuum is higher than  $10^4$ Pa or the temperature exceeds 200°C, NSK recommends ball screws and linear guides coated with molybdenum disulfide solid lubricant. Particle emissions pose other problems in addition to those associated with the degree of vacuum. To minimize particle emissions, NSK recommends ball screws and linear guides with soft metal (e.g., silver) solid lubricant coatings. We are presently evaluating the performance of our special fluororesin coating (LDF coating) for use with ball screws and linear guides.

## 2.5 High temperature environments

As synthetic resin is often applied to the components of standard ball screws and linear guides, their maximum operating temperature is generally 70~80°C for continual operation and 100°C for very short periods. If a heat-resistant coating is applied to the treated components instead of synthetic resin (even when the other components remain standard material), ball screws and

linear guides can withstand temperatures up to 150°C for continuous use and 200°C for short periods.

Many resin components are used for linear guides, but NSK created its basic heat-resistant linear guides for temperatures up to 150°C (200°C for a short time) by changing the end cap material to sintered metal powder and the bottom and side seal material to fluorine rubber. These linear guides are already used for welders, glass production facilities and heat treatment equipment. For a particular application in which spattering from welding was a problem, NSK prepared heat-resistant bellows to cover the rails. Naturally, for high-temperature environments, heat-resistant lubricant must be selected. NSK can apply its extensive experience and recommend the most suitable lubricant for a given application.

By applying further material and heat treatment enhancements, NSK can produce ball screws and linear guides that can withstand operating temperatures from 200 to 300°C.

## 2.6 Magnetic environments

When standard ball screws and linear guides are used in strong magnetic environments, e.g., where plasma lasers are used, they become magnetized and various problems result. To avoid such problems, NSK developed ball screws and linear guides made of a special nonmagnetic stainless steel (relative magnetic permeability  $\mu < 1.01$ ). While ceramics first come to mind when considering nonmagnetic material, they are more expensive than this special stainless steel. Even compared to the beryllium copper alloys used widely as nonmagnetic material, this special stainless steel is superior in terms of both hardness and cost. Ball screws and linear guides made of this stainless steel are not limited to use in strong magnetic environments. As residual magnetism can be suppressed to very low levels with ball screws and linear guides of this material, the ambient magnetic field is not disturbed. Consequently, these ball screws and linear guides are used in CT scanning devices, mine detectors and various other detecting and measuring instruments that rely on electromagnetism.

## 2.7 Radiative environments

Ball screws used in the control rod mechanisms of nuclear reactors are believed to be subject to the most severe radiation conditions. The highest reliability is required of these ball screws in order to safely control the nuclear reactor. Here too, NSK's ball screws have been used for a long time. In this application, not only is radiation strong, but in most cases very high temperatures of about 150~300°C are encountered. We selected a stainless steel best suited to such conditions. Radiation-resistant grease is used for lubricant when temperatures are not too high. Under high temperature and pressure, surrounding water is used as the lubricant. Besides control rod mechanisms, numerous NSK ball screws and linear guides are used in nuclear power plants.

### 3. Conclusion

Ball screws and linear guides are being utilized in a broadening range of environments and applications. Naturally, standard products cannot always meet the evolving needs of today's industry, so NSK constantly works to develop, evaluate and confirm new technologies that satisfy users in terms of reliability and cost. While resulting from years of work on special environment applications, the SPACEA Series presented here is continually evolving in response to new requirements. Be sure, therefore, to consult NSK before assuming that the use of ball screws or linear guides is impossible in a particularly harsh environment. We will work to provide an effective solution based on our extensive technology and experience, as well as comprehensive field and test data.



*Toshiharu Kajita*

# Bearings for Traction Gears

Toshio Suzuki  
Roller Bearing Technology Department  
Bearing Technology Center

## ABSTRACT

Tapered roller bearings have long been used in the traction gears that transmit power from motors to railway axles. As a result of the severe operating conditions of this application (extensive vibration, high temperatures and high rotational speeds), damage such as cage breakage, dimensional change of the inner ring, and seizure can occur. For this reason, tapered roller bearings for traction gears have special specifications that are different from those of bearings for general applications. In this report, I will first describe these special specifications, then present test results on newly developed tapered roller bearings with improved seizure resistance, and finally discuss recent technical trends in bearings for the traction gears of bullet trains.

## 1. Introduction

Railway vehicles include electric trains; steam, electric and diesel locomotives; and diesel, passenger and freight cars. Bearings used for railway vehicles primarily include those for axles, main motors and traction gears. In terms of railway technology, Japan is one of the most advanced countries in the world. More so than other countries with advanced railway technology, the overwhelming majority of rolling stock in Japan are powered by electricity. The total number of cars in Japan, including bullet trains (*shinkansen*), JR (Japan Railways) trains, private railways, and municipally operated trains, exceeds 40 000. The various traction gears used in Japan are very similar and bearings of the same type have long been used in them. These bearings have special specifications to cope with the severity of their operating conditions while at the same time require improved performance and reliability to enable higher speeds and reduced maintenance for today's electric railway vehicles.

## 2. Traction Gears

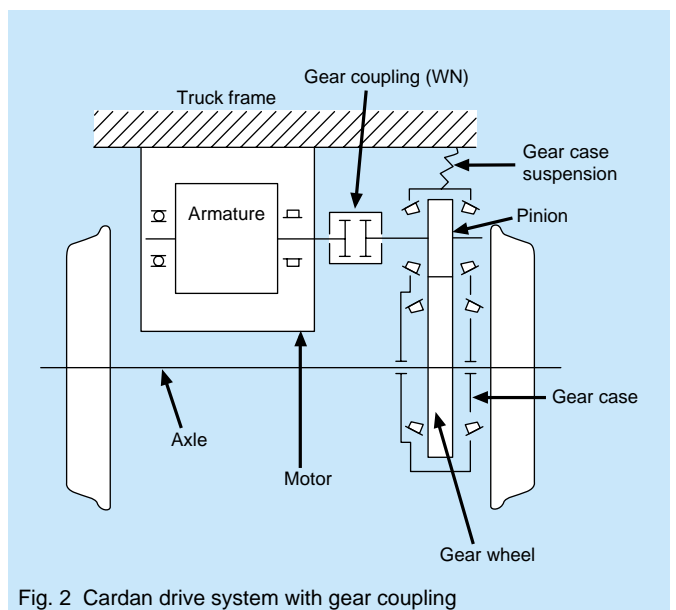
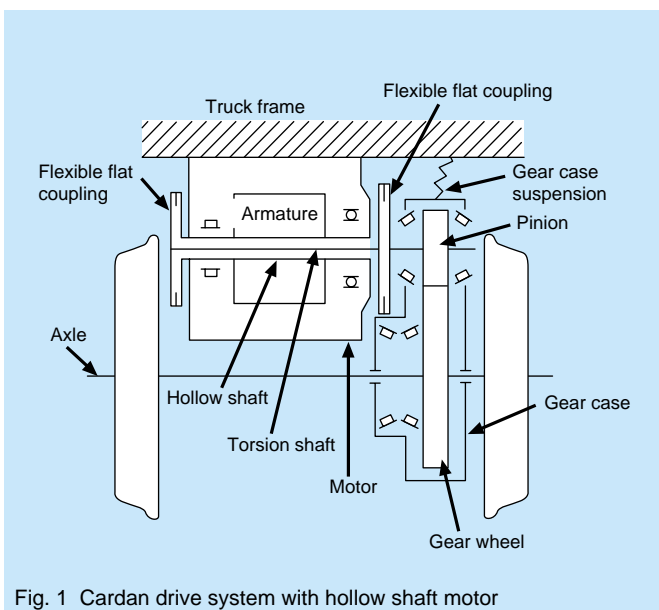
### 2.1 Traction gear systems

The drive system of a railway vehicle transmits power from an electric motor to an axle via a set of gears. These gears are usually supported by tapered roller bearings.

The train drive systems used in Japan are mostly of the type mounted on the underside of trucks and are either parallel Cardan drive systems with hollow shaft motors (Fig. 1) or parallel Cardan drive systems with gear couplings (Fig. 2). Typically, those with hollow shaft motors are used on the narrow-gauge rails (1 067 mm) used by JR and most private railways, while those with gear couplings are used on the standard-gauge rails (1 435 mm) used by bullet trains and some private railways.

### 2.2 Types of bearings used in traction gear systems

For the pinion in the drive systems of both the Cardan hollow shaft type and gear coupling type, single-row tapered roller bearings mounted facing inward are used on either side of the pinion. Very often, bearings with rollers



tapered at a steep gradient are used because the pinion teeth are single helical (at a torsional angle of 18 to 35°).

For the gear wheel in Cardan drive systems with a gear coupling, single-row tapered roller bearings facing inward are used on either side of the gear. For the gear wheel in Cardan drive systems with a hollow shaft motor, on one side of the gear either single-row tapered roller bearings arranged back-to-back are used or a double-row tapered roller bearing is used (Figs. 3 and 4).

### 3. Problems of Bearings for Traction Gears and Countermeasures

The operating conditions of tapered roller bearings in traction gears are very severe. The bearings are subjected to the vibration of the drive system, vibration caused by

engagement between the pinion and the gear wheel, relatively high rotational speeds, and high temperatures under oil-splash lubrication. As a consequence of these harsh conditions, many problems have arisen over the years. The following sections describe some of the more common problems that have occurred with tapered roller bearings used in traction gears.

#### 3.1 Cage fracture

Cages in bearings for drive systems are prone to fracture because of the high vibration and frequent shock loads applied to them. Measures to minimize the possibility of fracture include increasing the thickness of the cages and reducing the number of rollers in the bearing. Additionally, nitro-carburizing treatment, which hardens cage surfaces and reduces wear between the rollers and cage bars, is applied to some cages (Figs. 5 and 6).

Since 1984, NSK has utilized its nitro-carburized cages

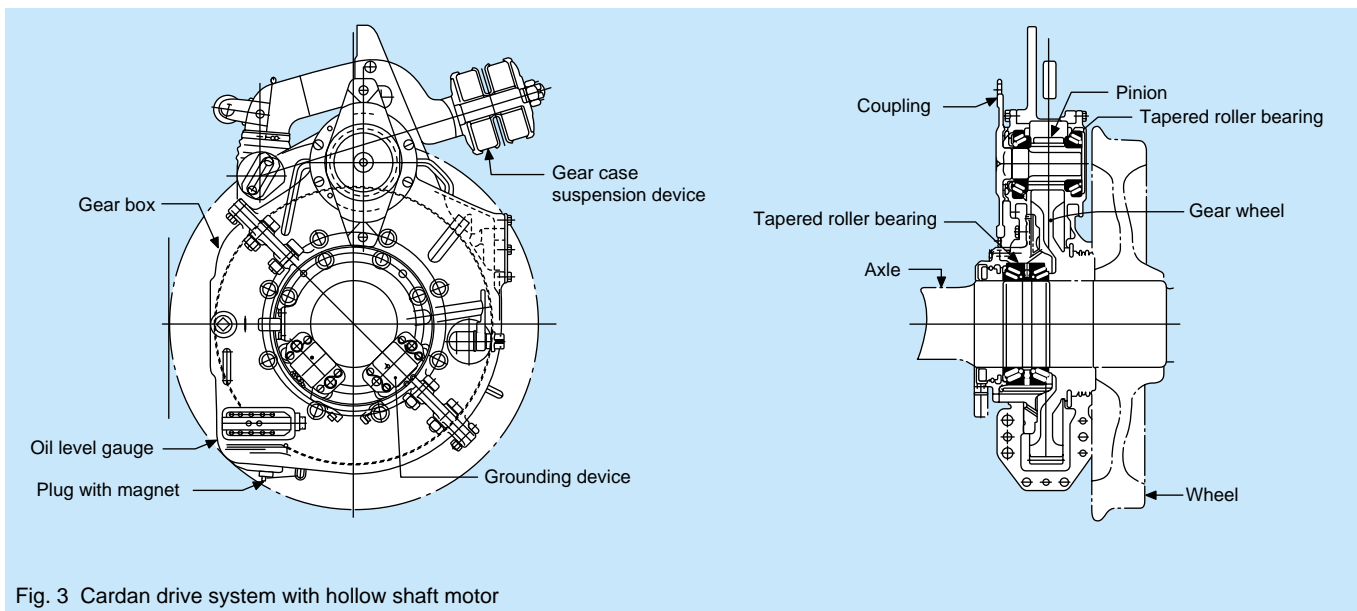


Fig. 3 Cardan drive system with hollow shaft motor

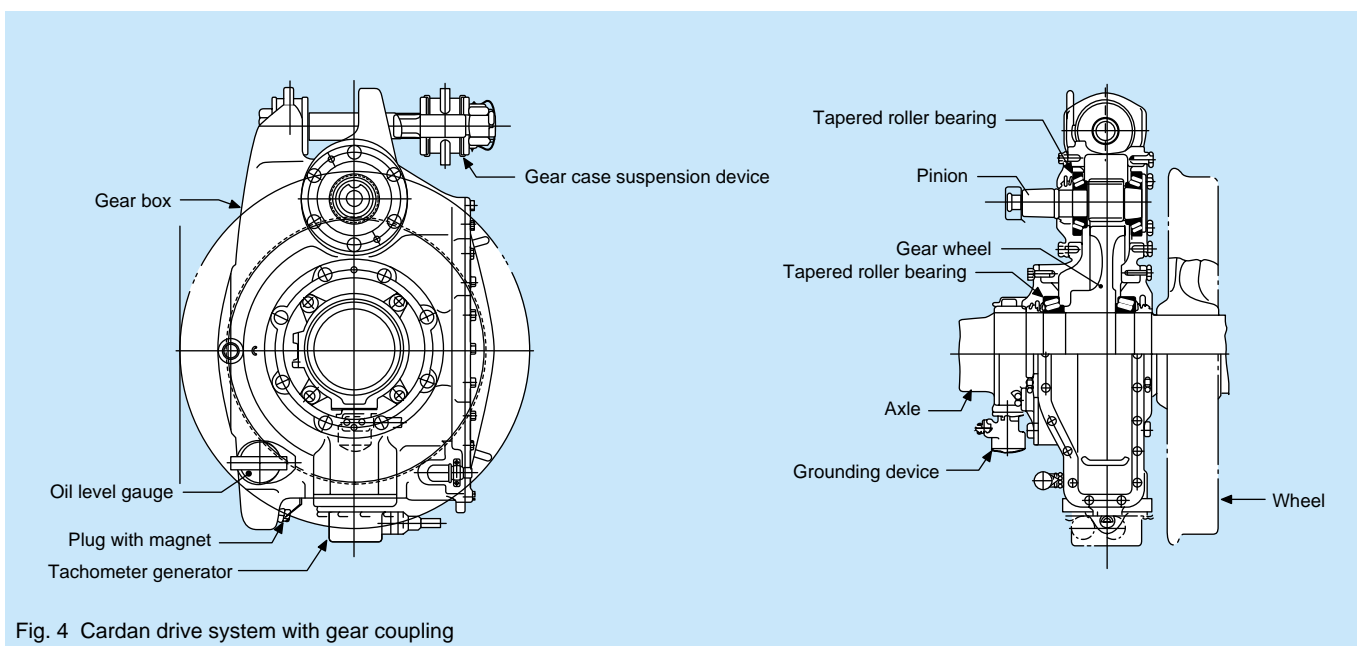


Fig. 4 Cardan drive system with gear coupling

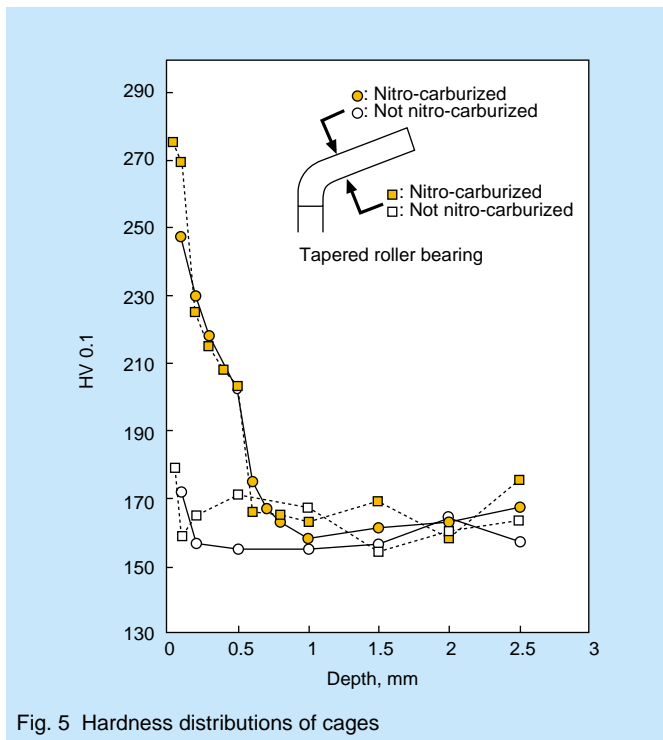


Fig. 5 Hardness distributions of cages

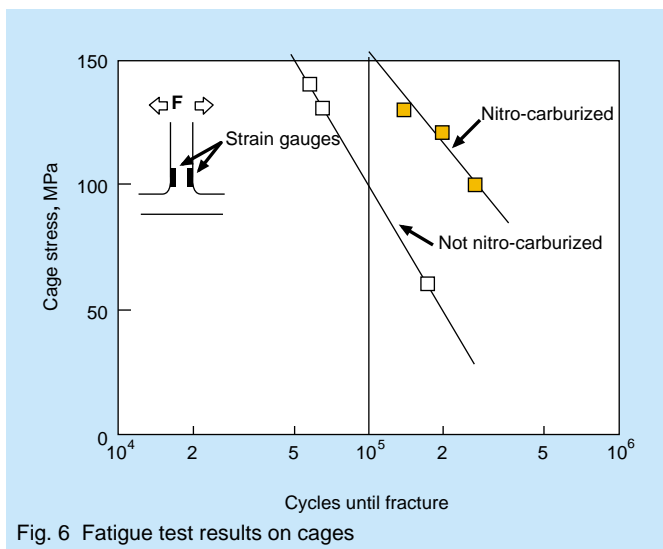


Fig. 6 Fatigue test results on cages

with higher fatigue strength in bearings for the traction gears of railway vehicles for some private rail companies. More recently, nitro-carburized cages have begun being used in the bearings for the pinions of the drive systems of all bullet trains of Series 300 and higher.

### 3.2 Inner ring creep

As traction gear bearings are lubricated by oil splashed from the gear wheel, the bearings in both the pinion and the gear wheel are heated to relatively high temperatures. When a bearing is operated under these lubricating conditions for a long period of time, its inner ring may swell and creep relative to the vehicle axle. Bench tests performed using full-size gear units identical to those actually used in bullet trains indicated that the temperatures of the bearings for both the pinion and the

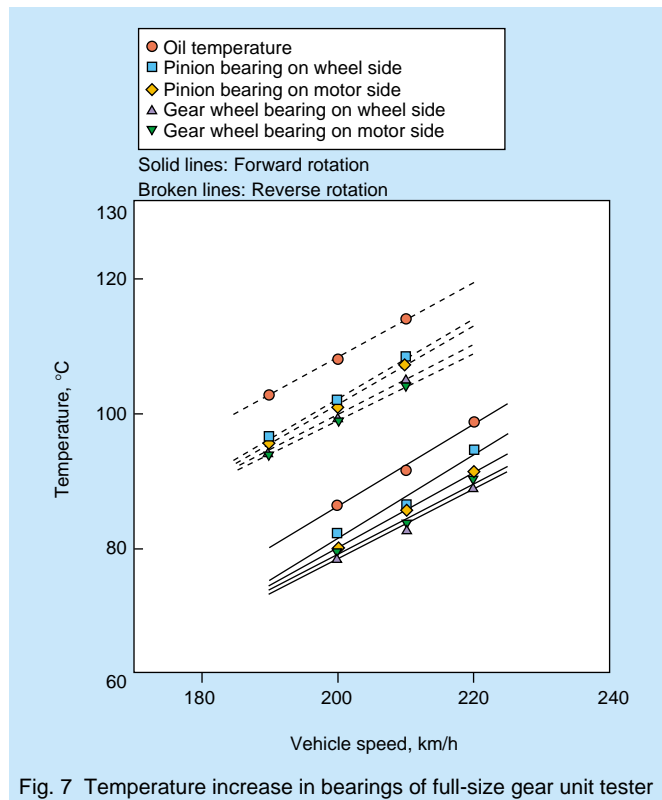


Fig. 7 Temperature increase in bearings of full-size gear unit tester



Photo 1 Full-size gear unit tester (0 Series bullet trains)

gear wheel exceed 100°C when the gear unit operates in the reverse direction and the flow of lubricating oil is less than during forward operation (Photo 1 and Fig. 7). In response to these high operating temperatures, heat treatment to improve dimensional stability is applied to the inner rings of bearings for both the gear wheels and the pinions. In addition, the inner rings of bearings for the gear wheels of the drive systems in recent bullet trains are made of carburized steel and are fitted on the axle with greater interference to help minimize creep.

### 3.3 Pinion bearing seizure

The most typical type of damage to pinion bearings in drive systems is seizure between the large rib (cone back face rib) of the inner ring and the end faces of the rollers. This seizure is particularly liable to occur soon after a drive system begins operating in winter, when the supply

of lubricating oil to the pinion bearings may be insufficient because of the low temperatures and the high viscosity of the oil. As long as the bearing is well lubricated, seizure may not occur even if the bearing is operated at higher than usual working speeds and loads. In a high-speed rotation test of QT7 pinion bearings (inside diameter: 75 mm, outside diameter: 160 mm) used in JR railway vehicle drive systems, no seizure occurred at 10 000 rpm and  $PV = 557 \text{ MPa}\cdot\text{m/s}$  when the bearings were lubricated with 4 liters/minute (Fig. 8).

Also in cold weather, when the temperature of entire drive systems becomes low while they are idle, seizure of the pinion bearings may occur after starting operation because of the different rates of temperature rise of the outer and inner rings, which cause the axial clearance to be eliminated and lead to excessive load being applied to the large rib of the inner ring and the end faces of the rollers.

Fig. 9 shows  $PV$  values of pinion bearings operated in actual conditions of railway vehicle traction gears.

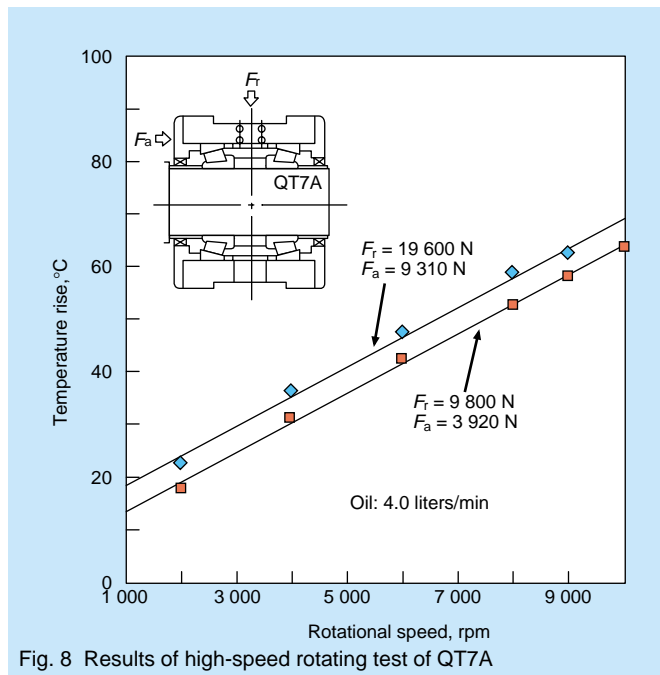


Fig. 8 Results of high-speed rotating test of QT7A

#### 4. Pinion Bearings with Improved Seizure Resistance for Traction Gears

Tapered roller bearings for the pinions of drive systems are designed to be highly resistant to seizure even under severe lubricating conditions. Design features to this end include the improved surface roughness of the large rib of the inner ring and the roller end faces, and the improved shape of the roller ends, which together ensure better formation of oil film between the roller ends and the rib. While the preceding section stated that seizure would not occur under actual drive system operating conditions if the bearings were kept well lubricated, in reality, even these pinion bearings with high seizure resistance have experienced seizure troubles from time to time in winter, when lubrication performance tends to be degraded. In

response, NSK has developed pinion bearings with even higher seizure resistance. In the following sections, we describe the bearings and the tests conducted on them to assess their seizure resistance.

##### 4.1 Test method, bearings and conditions

###### (1) Test Method

The tester was accelerated up to the test speed at a constant rate of 1 000 rpm per minute. After stabilization of the bearing temperature, the oil lubrication was cut off. Seizure resistance was evaluated in terms of the length of time until seizure occurred.

- 1) Lubricating oil: AP Wide Gear LW80/90
- 2) Lubrication: 1 liter/min (forced circulation lubrication)
- 3) Lubricating oil temperature: 50°C (constant)

###### (2) Test Bearings

Two types of bearings currently used by JR were tested:

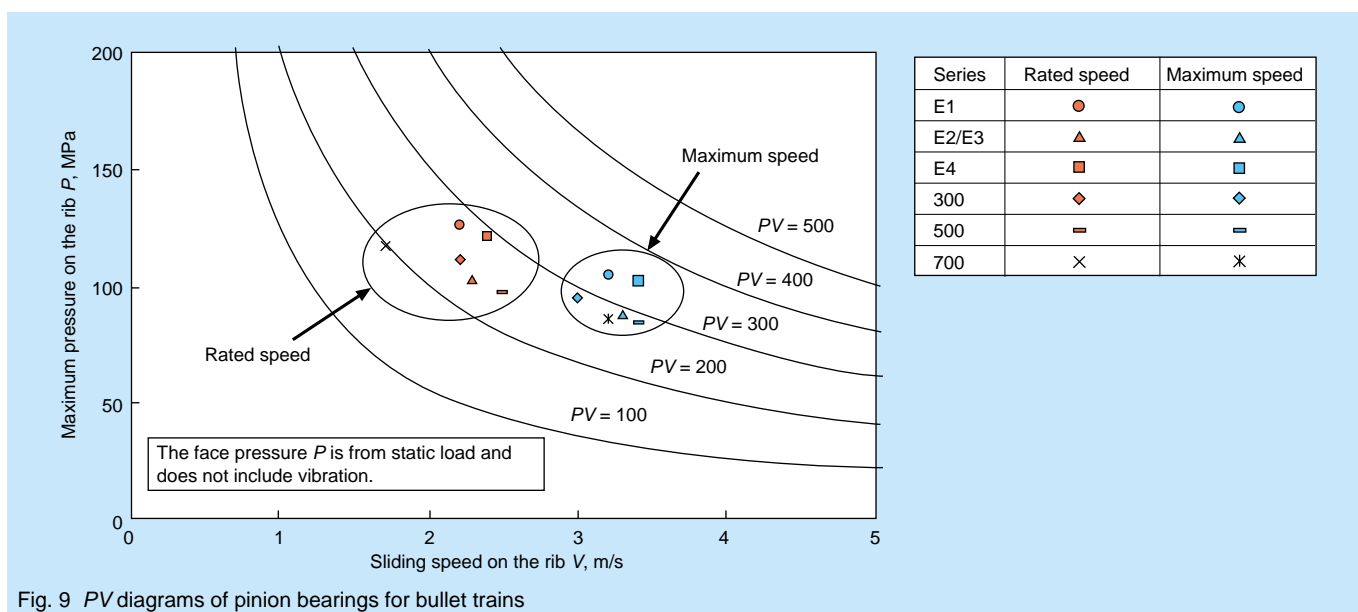


Fig. 9 PV diagrams of pinion bearings for bullet trains

- 1) QT7A  
(inside diameter: 75 mm, outside diameter: 160 mm)  
Mostly used for JR commuter and subway trains
- 2) QT9A  
(inside diameter: 70 mm, outside diameter: 150 mm)  
Mostly used for JR limited express trains

(3) Testing Conditions

In actual traction gears, radial and axial loads are applied simultaneously to pinion bearings due to the meshing between the pinion and gear wheel. In this test, however, only axial load was applied. Enough axial load was applied to produce pressure between the large rib of the inner ring and the ends of the rollers that was equivalent to normal operating conditions, when both axial and radial loads are applied. The QT7A test bearings were operated at a maximum speed while the QT9A bearings were operated at a rated speed based on actual service.

- 1) QT7A  
Conditions:  $F_a = 16.7$  kN,  $N = 3\ 810$  rpm  
 $PV = 579$  MPa·m/s (maximum speed)
- 2) QT9A  
Conditions:  $F_a = 13.7$  kN,  $N = 2\ 500$  rpm  
 $PV = 284$  MPa·m/s (rated speed)

#### 4.2 Testing equipment

Fig. 10 depicts the test equipment. Axial load was hydraulically applied through the tapered roller bearing located for support on the opposite side of the test bearing. The measurement items were the outer ring outside surface temperature, the temperature of the large rib of the inner ring, and dynamic torque (including that of the support bearing). The temperature of the large rib of the inner ring was measured using a slip ring at the end of the spindle. Dynamic torque was measured by a torque meter installed between the tester and the pulley.

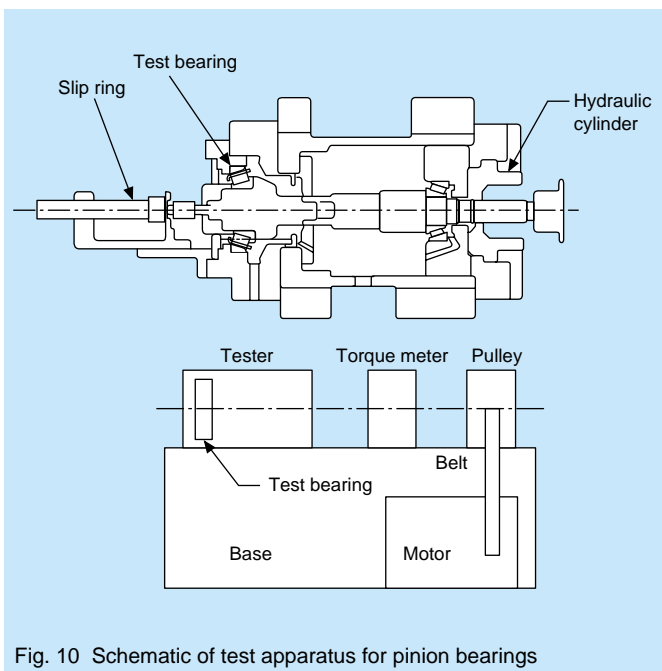


Fig. 10 Schematic of test apparatus for pinion bearings

#### 4.3 Test results

The seizure resistance of the test bearings was increased by improving the surface roughness of both the large rib of the inner ring and the roller ends, and by modifying the shape of the roller ends and rolling contact surfaces. The shape of the roller ends in contact with the large rib of the inner ring is designed to be less prone to seizure particularly when the rollers become skewed during operation.

In the tests, the newly designed bearings demonstrated greatly improved seizure resistance. Under a high  $PV$  value, the QT7A bearings operated more than 10 times longer than bearings currently in use (Fig. 11). Under a lower  $PV$  value, the QT9A bearings did not seize during the entire test period of 600 seconds, outlasting the currently used bearings approximately five-fold (Fig. 12).

### 5. Features of Recent Bearings for Traction Gears

#### 5.1 Bearings for bullet train drive systems

The drive systems in bullet trains are parallel Cardan drive systems with gear couplings. Tapered roller bearings are used for both their pinions and gear wheels (Table 1). The operating speed of the bearings for the pinions has been increasing in line with the higher speeds of each new series of bullet trains. The pinion bearings for 300 Series bullet trains (QT9B;  $\phi 70$  mm  $\times$   $\phi 150$  mm  $\times$  38 mm) are operated at 5 470 rpm,  $d_m N = 600\ 000$ , when the trains run at their maximum speed. Nonetheless, the temperature rise of these bearings at such speeds is not so high because they are smaller than the QT4A and QT18 bearings used in older bullet trains, and because aluminum is used for the gear casings to improve cooling. As to cages, either QT9B-1 cages, whose thickness is 4.5 mm (0.5 mm thicker than cages in bearings for older trains) or QT9B-2 cages, which are nitro-carburized but have the same thickness as cages in bearings for older trains, are used in the pinion bearings for 300 Series bullet trains.

QT9B-2 cages are used in the pinion bearings for the newly developed E2 and E3 Series bullet trains of JR East Japan and the 500 Series bullet trains of JR West Japan. Nitro-carburized cages are also used in the QT31 pinion bearings for the drive systems of the E1 and E4 Series bullet trains of JR East Japan.

The bearings for the gear wheels of the E1, E2, E3 and E4 Series bullet trains of JR East Japan have a phosphate-coated inner ring to avoid scratching the axle when the inner ring is removed. The effectiveness of the phosphate coating in preventing scratching of axles was verified with the QT19-1 bearing for the gear wheels of 200 Series bullet trains of JR East Japan. Since then, phosphate-coated inner rings have been used in all newly developed bullet trains.

#### 5.2 New type of bearings for traction gears

As noted, most bearings used in railway train drive gear

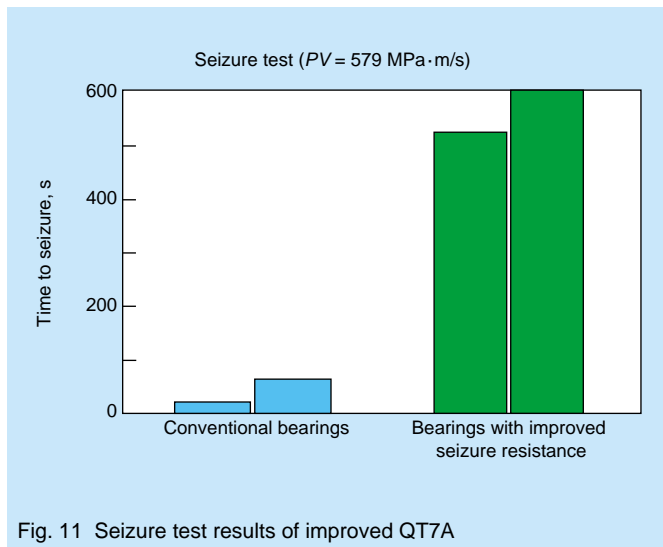


Fig. 11 Seizure test results of improved QT7A

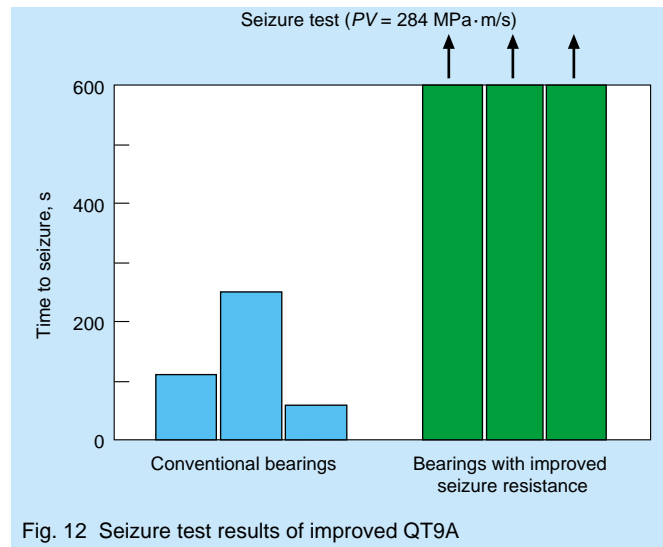


Fig. 12 Seizure test results of improved QT9A

Table 1 Driving gear bearings for bullet trains

Bullet train	Pinion bearing		Gear wheel bearing	
	Bearing number	I.D. by O.D., mm	Bearing number	I.D. by O.D., mm
Series 0 (Kodama)	QT4A	80 × 170	QT5	210 × 320
Series 100 (Hikari)	QT4A	80 × 170	QT24	210 × 320
Series 200 (Tohoku & Joetsu)	QT18	85 × 180	QT19-1	214 × 330
Series 300 (Nozomi)	QT9B	70 × 150	QT26	195 × 280
Series E1 (MAX)	QT31	70 × 150	QT32	218 × 315
Series E2 (Hokuriku)	QT9B	70 × 150	QT34	202 × 290
Series E3 (Komachi)	QT9B	70 × 150	QT34	202 × 290
Series E4 (MAX)	QT31	70 × 150	QT35	215 × 315
Series 500 (Nozomi)	QT9B	70 × 150	QT26	195 × 280

systems are tapered roller bearings. Tapered roller bearings are used in combinations and therefore require accurate adjustment of their axial clearance. With pinion bearings, too much axial clearance increases susceptibility to vibration from the meshing of gear teeth and thus raises the possibility of cage damage. Not enough axial clearance may cause large temperature differences between the outer and inner rings during the initial operation of a bearing in cold weather, resulting in still smaller axial clearance or even interference and subsequent seizure. For this reason, axial clearance is strictly controlled during the assembly process.

Recently, bearings requiring no axial clearance adjustment are used. These are combinations of 3-point or 4-point contact ball bearings and cylindrical roller bearings. In these bearing combinations, axial clearance is determined by the internal clearance of the ball bearing and needs no adjustment during the assembly process.

## 6. Conclusion

Today's quickly advancing railway technology permits operation of commuter trains on tighter schedules and enables bullet trains as well as local trains to achieve higher and higher speeds. This, in turn, creates stricter requirements for traction gear bearings. In the long

history of railway development in Japan, traction gear bearings have presented numerous problems and challenges and have been modified and improved in response. Nonetheless, bearing damage similar to that experienced and solved in the past is reoccurring from time to time nowadays due to the faster acceleration and deceleration of railway drive systems and the tighter schedules and higher speeds of train operation. As a result, traction gear bearings are expected to achieve still higher degrees of reliability. Also, in response to the need to reduce the weight of railway vehicles, railway bearings are expected to be smaller and lighter. Bearings must not only be made smaller, but also better bearing materials must be developed and utilized to ensure adequate service life. NSK will continue its efforts to improve the performance of railway traction gear bearings to meet the changing needs of the market.



Toshio Suzuki

# Inner Ring Fracture Characteristics under Rolling Contact

Kiyoshi Hirakawa, Norifumi Ikeda, Shigeru Okita and Akihiro Kiuchi  
Basic Technology Research & Development Center

## ABSTRACT

Inner ring fracture sometimes occurs if a rolling bearing is mounted with relatively high hoop stress. NSK has developed a life test method for inner ring fracture in order to study and develop appropriate materials and effective heat treatment processes. This method enables accurate simulation of actual inner ring fracture by providing a minute half-ellipse fatigue crack at a selected "origin point" on the inner ring raceway.

Using this method, life test results on inner ring fracture caused by hoop stress showed that inner ring fracture life and hoop stress correlate relatively well. Next, the effect of material and heat treatment on inner ring fracture life was studied. It was confirmed that compressive residual stress is effective in extending inner ring fracture life. In particular, it was shown that a fatigue crack in M50NiL at 280 MPa hoop stress propagates negligibly.

Applying results obtained through this test method, NSK developed a special steel and heat treatment ("TL" specification) that results in excellent dimensional stability and superior inner ring fracture life and rolling fatigue life, even under conditions of high temperature and contaminated lubrication.

## 1. Introduction

The inner ring of a roller bearing mounted with relatively high hoop stress sometimes fractures in the axial direction after a certain period of usage. Particularly in the aerospace industry, demand is high for increased resistance to inner ring fracture as bearings in today's jet engines are subjected to ever-higher centrifugal forces. Fatigue cracking and ultimately in some cases, fracture, are believed to result from repeated rolling stress being applied to an inner ring raceway that is under tensile stress caused by hoop and centrifugal stress. Fatigue cracking is thought to originate at surface or subsurface stress concentrations caused by nonmetallic inclusions, flaking or rust. Fig. 1 shows an example of the inner ring fracture of a spherical roller bearing with a tapered bore used in a paper-making machine.

In order to develop effective materials and heat treatment methods that improve inner ring fracture

resistance, it is necessary to have suitable evaluation technology. Tensile, impact and fracture toughness testing are not effective for evaluating inner ring fracture resistance. Concerning this problem, Aberbach and co-researchers used Compact Tension Specimens to analyze the influence of residual stress on the rate of crack propagation, as well as consider compressive residual stress.<sup>1)</sup> Clark performed tests under hoop stress after using electrical discharge machining to introduce semi-circular defects ( $0.36 \times 0.71$  mm) onto the inner ring raceway surfaces of cylindrical roller bearings made of M50 and M50NiL steel.<sup>2)</sup> Under hoop stress of 30 ~ 38 ksi (206 ~ 261 MPa), the inner ring of the M50 bearing fractured as a result of the defect while that of the M50NiL bearing did not. Additionally, Pearson, based on both experiments and an analysis of the literature, discussed the stress limits of crack propagation in AISI52100 and M50NiL steel under hoop stress in the range of 170 ~ 400 MPa.<sup>3)</sup> However, he did not discuss the

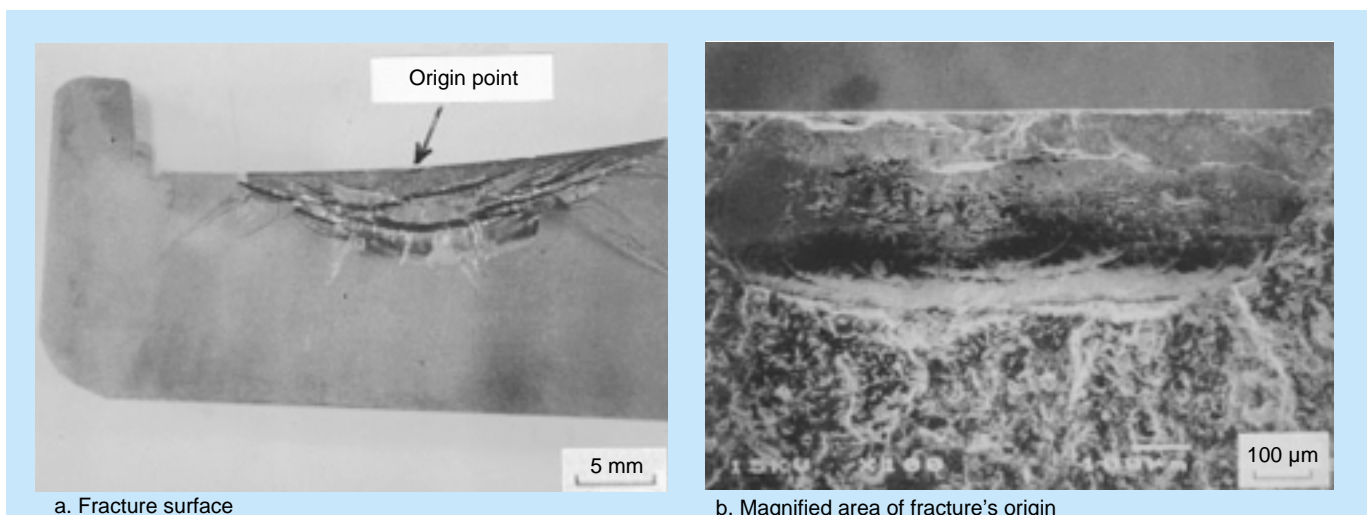


Fig. 1 Example of inner ring fracture of a spherical roller bearing

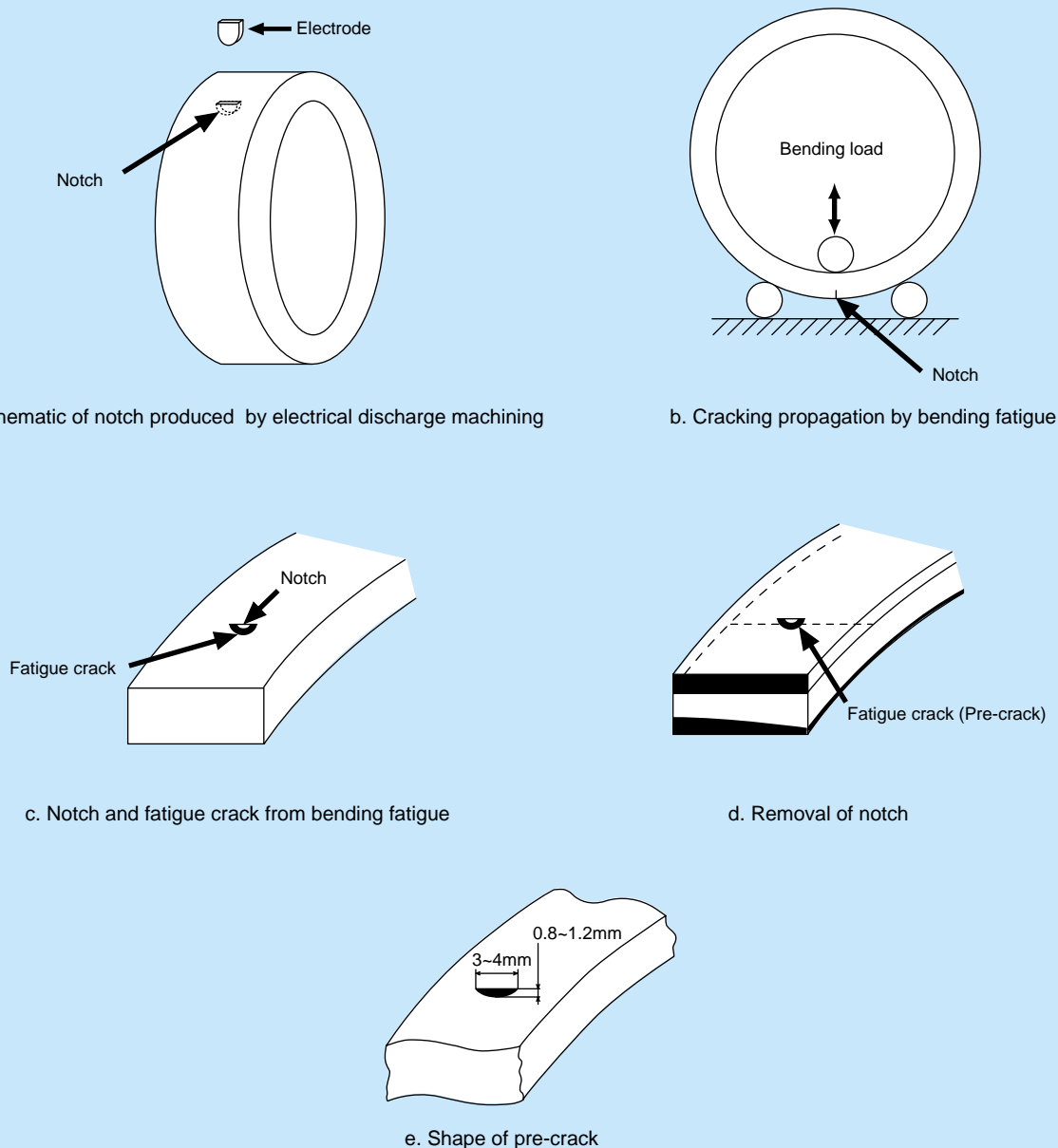


Fig. 2 Making a fatigue pre-crack

relationship between inner ring fracture life and hoop stress.

As summarized above, no data was found in the literature to connect hoop stress or residual stress and inner ring fracture life. Considering the need for such data and understanding the necessity of creating a method that produces inner ring fracture without generating flaking, NSK developed an inner ring fracture life test that can reproduce and confirm the morphology of inner ring fractures that occur during actual applications. Using this method, we conducted tests to determine the relationship between hoop stress, residual stress and inner ring fracture life in roller bearings. In this report, we present our method for inner ring fracture life testing, discuss test results on various types of steel (including NSK's own TL-specification steel), and analyze how hoop stress and residual stress affect inner ring fracture life.

## 2. Procedure for Inner Ring Fracture Life Tests

Inner ring fracture and flaking of rolling bearings originate from stress concentrations caused by dents, rust, or nonmetallic inclusions. When the hoop stress of the inner ring is low and the stress concentration is at the subsurface site of a nonmetallic inclusion, a fatigue crack will initiate from the nonmetallic inclusion, propagate around the bearing's circumference almost parallel to the raceway surface and flaking will occur. If hoop stress is high, the fatigue crack will propagate perpendicularly to the raceway surface (i.e., down toward the shaft), expand axially and eventually lead to inner ring fracture.<sup>4)</sup>

It is necessary to be able to make artificial crack origin points of a consistent size and shape in order to evaluate

the effectiveness of heat treatments and materials against inner ring fracture. As defects made just by electric discharge processing can result in flaking originating from the defect's edge, NSK has developed a method to introduce fatigue "pre-cracks" to avoid flaking. Fatigue pre-cracks are half-ellipse-shaped and positioned perpendicularly to the raceway surface in the center of the inner ring raceway of cylindrical roller bearings (NU216). There are three steps in the process of making a fatigue pre-crack. First, a half-ellipse shaped notch is made on the raceway surface by electrical discharge processing (Fig. 2-a). Then, by applying bending fatigue, cracking propagates from the notch (Figs. 2-b and c). Finally, the notch is removed by machining leaving only the fatigue pre-crack (Figs. 2-d and e). The pre-cracks in these tests had a length of 3 ~ 4 mm and a depth of 0.8 ~ 1.2 mm. The width of the pre-cracks was so small that it could only be detected by magnetic particle detection. Generally speaking, rolling contact stress causes fatigue cracking to propagate from the pre-crack. In some cases this ultimately leads to fracture.

In our inner ring fracture testing, an inner ring with a fatigue pre-crack is mounted on the tapered shaft of the test rig (Fig. 3). Both hoop stress and load are applied

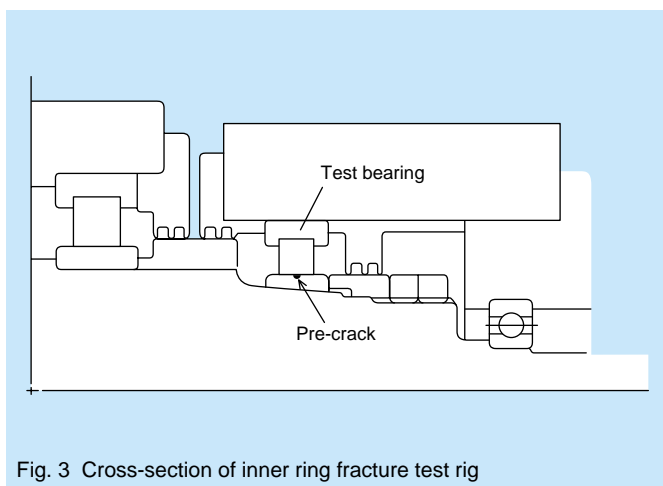


Fig. 3 Cross-section of inner ring fracture test rig

during the rotation test. The tests discussed here were conducted with bearing loads of 19 600 N ( $P/C = 0.19$ ) and 29 400 N ( $P/C = 0.28$ ) at a rotational speed of 1 800 rpm. Fracture life ( $N$ ) in these tests is defined as the number of revolutions until the inner ring is fractured or bearing vibration becomes excessively high from the propagation of the pre-crack into a fatigue crack over the width of the raceway surface. Hoop stress is calculated from the amount of expansion of the bore of the inner ring that is mounted on the tapered shaft. Hoop stress is also measured using a strain gauge. The calculated values correlate well with measured ones.

### 3. Results of Inner Ring Fracture Life Tests

Hoop stress was the primary variable in these tests because it is the most important factor influencing inner ring fracture life in most applications. Table 1 shows the hardness, heat treatment, and material of the inner rings used in these tests. Fig. 4 presents the results of inner ring fracture life tests.

#### 3.1 Results of AISI52100 bearing steel inner ring fracture life tests

Fig. 5-a shows the pre-crack in an inner ring made of standard 52100 bearing steel before testing. Fig. 5-b shows the inner ring after fracture and Fig. 5-c shows the fracture surface. There are three areas labeled in Fig. 5-c: A is the area of the pre-crack, B is the area that progressively fractured due to rolling contact fatigue, and C is where the fracture rapidly progressed.

Because inner ring fracture often occurs in applications with higher temperatures and hoop stress, high-temperature-tempered 52100 inner rings and bainite-treated 52100 inner rings were tested in addition to standard heat-treated ones. The results are included in Fig. 4. As shown in the figure, the bainite-treated 52100 inner rings exhibited much longer fracture life than either

Table 1 Materials, heat treatment and hardness

No.	Classification	Material	Chemical composition					Heat treatment	Hardness
			C	Cr	Mo	V	Ni		
1	Bearing steel, standard heat treatment	AISI52100	1.0	1.5	—	—	—	840°C, oil quenching, 180°C tempering	HRC 62.5
2	High-temperature-tempered bearing steel	AISI52100	1.0	1.5	—	—	—	840°C, oil quenching, high-temperature tempering	HRC 60
3	Bainite-treated bearing steel	AISI52100	1.0	1.5	—	—	—	850°C, 240°C salt quenching (4 hrs)	HRC 59
4	High-speed steel for high-temperature bearings	M50	0.8	4.0	4.2	1.0	—	1100°C, oil quenching, 550°C tempering	HRC 62
5	Carburized high-speed steel for high-temperature bearings	M50 NiL	0.13	4.1	4.2	1.2	3.4	Carburizing, 1100°C, oil quenching, 550°C tempering	Raceway surface HRC 62 Core HRC 38
6	High-temperature-tempered carburized steel	SAE5120	0.2	1.0	—	—	—	Carburizing, high-temperature tempering	HRC 59.5
7	TL specification steel	Newly developed, case-hardened steel	Patent pending					Carbo-nitriding, high-temperature tempering	HRC 61

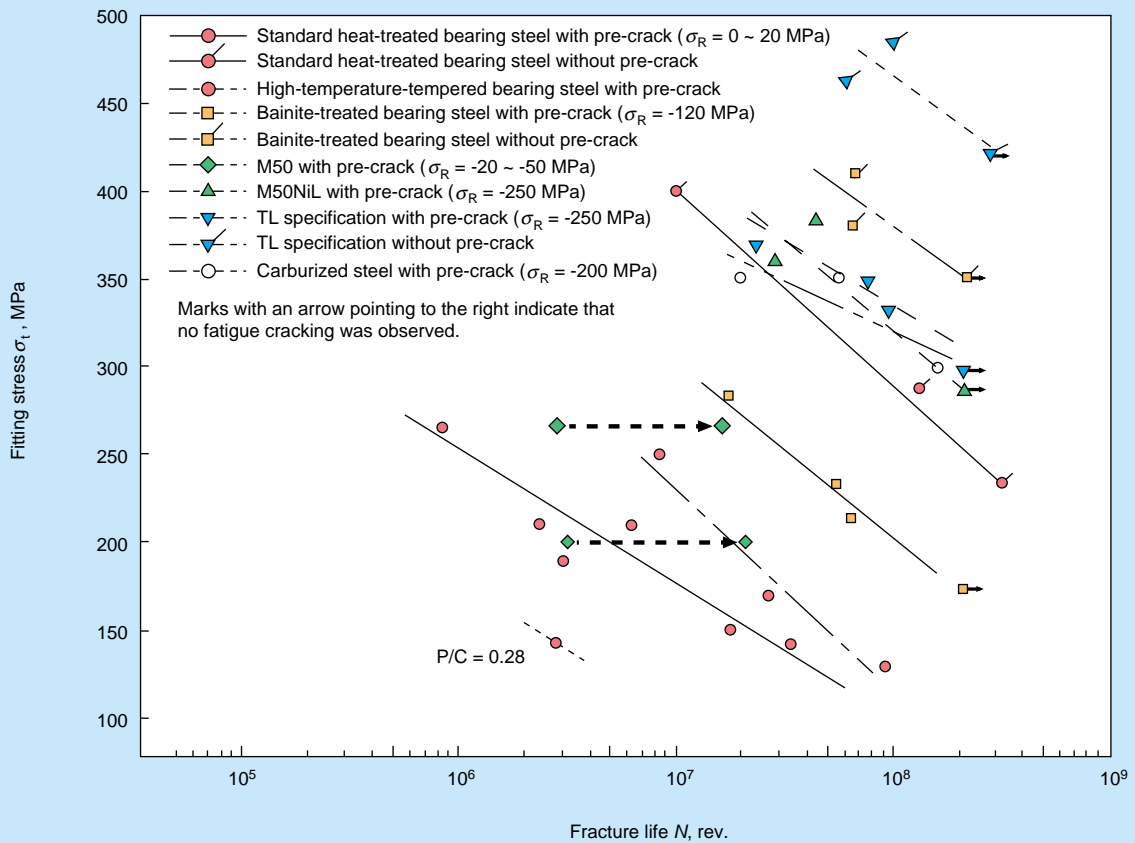
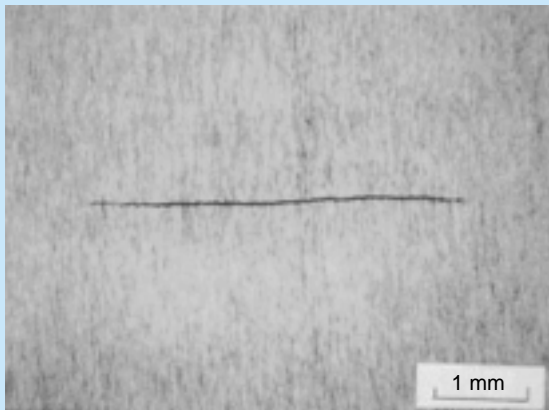
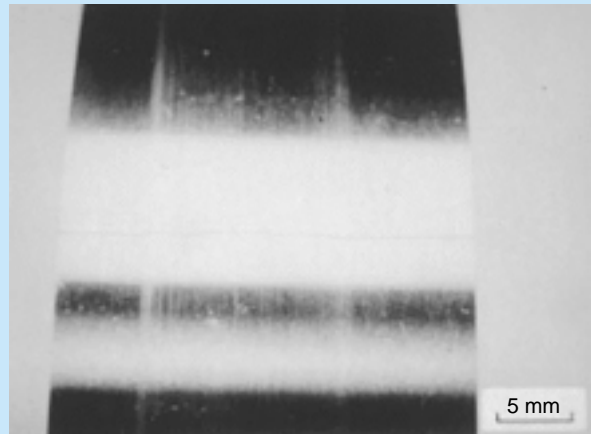


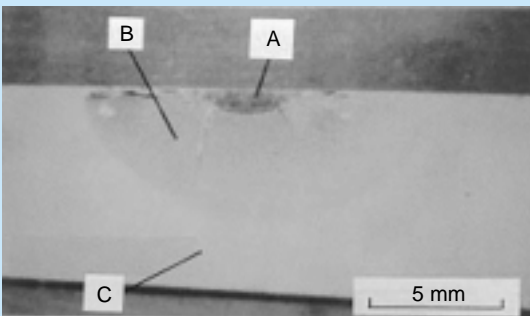
Fig. 4 Results of inner ring fracture test ( $P/C = 0.19$ )



a. Pre-crack (magnetic particle detection image)



b. Inner ring after fracture



c. Fracture surface (A-Pre-crack, B-Fatigue cracking, C-Section of rapid fracture)

Fig. 5 Pre-crack and inner ring fracture of 52100 inner ring (Standard heat treatment, Hoop stress  $\sigma_t = 210$  MPa,  $N = 6 \times 10^6$  rev.)

the standard heat-treated or high-temperature-tempered inner rings. This result is attributed to the higher compressive stress in the surface of the bainite-treated inner rings. Overall, the test results indicate a good correlation between hoop stress ( $\sigma_t$ ) and inner ring fracture life ( $N$ ) and show that inner ring fracture life decreases with increasing bearing load.

### 3.2 Results of M50 inner ring fracture life tests

M50 is a bearing steel for high-temperature applications. It is used for bearings, such as those in gas turbines and jet engines, that exceed operating temperatures of 200°C.

Testing of M50 inner ring fracture life was conducted on two bearings at two levels of hoop stress: 200 MPa and 270 MPa. In both bearings, fatigue cracks propagated almost over the entire raceway width and vibration increased after about  $N = 3 \times 10^6$  revolutions. As testing continued, the inner ring under hoop stress of 270 MPa fractured at  $N = 1.5 \times 10^7$  revolutions while that under hoop stress of 200 MPa managed  $N = 2.2 \times 10^7$  revolutions without fracturing before the test was discontinued due to excessive vibration. As Fig. 4 shows, the inner ring fracture life of M50 is almost equivalent to 52100. However, comparing Figs. 5-b and 6-b, the condition of the fatigue cracking on the raceway surface of the M50 inner ring is different from that of the 52100 inner ring. The fatigue crack of the 52100 inner ring propagated in an almost straight line in the axial direction and then the

inner ring fractured (Fig. 5-b), whereas the fatigue crack of the M50 inner ring stopped at the raceway width and then propagated like flaking (Fig. 6-b).

The circumferential sections of the 52100 and M50 inner rings in Figs. 7-a and b show how the fatigue cracks developed. The fatigue crack of the 52100 inner ring is almost straight while that of the M50 inner ring branches out in different directions. The nature of the M50 fatigue crack is believed to be due to M50's high tempering temperature.

### 3.3 Results of M50NiL inner ring fracture life tests

M50NiL is case-hardened M50 steel that was developed for the high rotating speeds of jet engine bearings. Because M50NiL has lower carbon content and contains Ni, its core has greater toughness and its case higher compressive residual stress than M50.

M50NiL exhibited longer inner ring fracture life than both 52100 and M50. Virtually no fatigue cracking was observed after  $N = 1.7 \times 10^8$  rotations under hoop stress of 280 MPa. When the hoop stress was raised to 390 MPa and after  $N = 5 \times 10^7$  rotations, a fatigue crack propagated from the pre-crack across the raceway width but the inner ring did not fracture (Fig. 8). Similar to the fatigue crack in the M50 inner ring, the fatigue crack in the M50NiL ring branches out in different directions (Fig. 7-c).

It is believed that the higher compressive residual stress (-250 ~ -300 MPa) of M50NiL is primarily responsible for

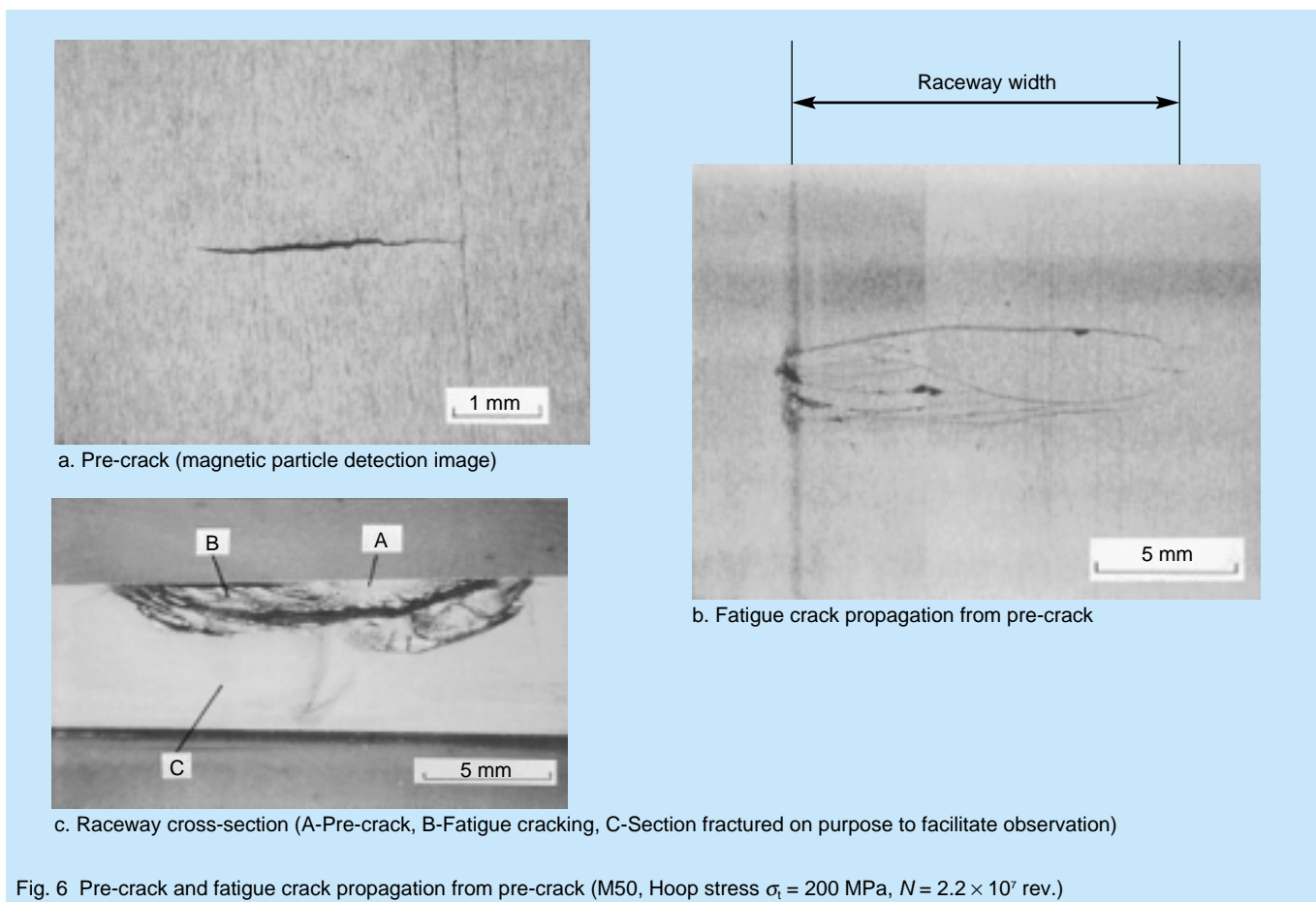
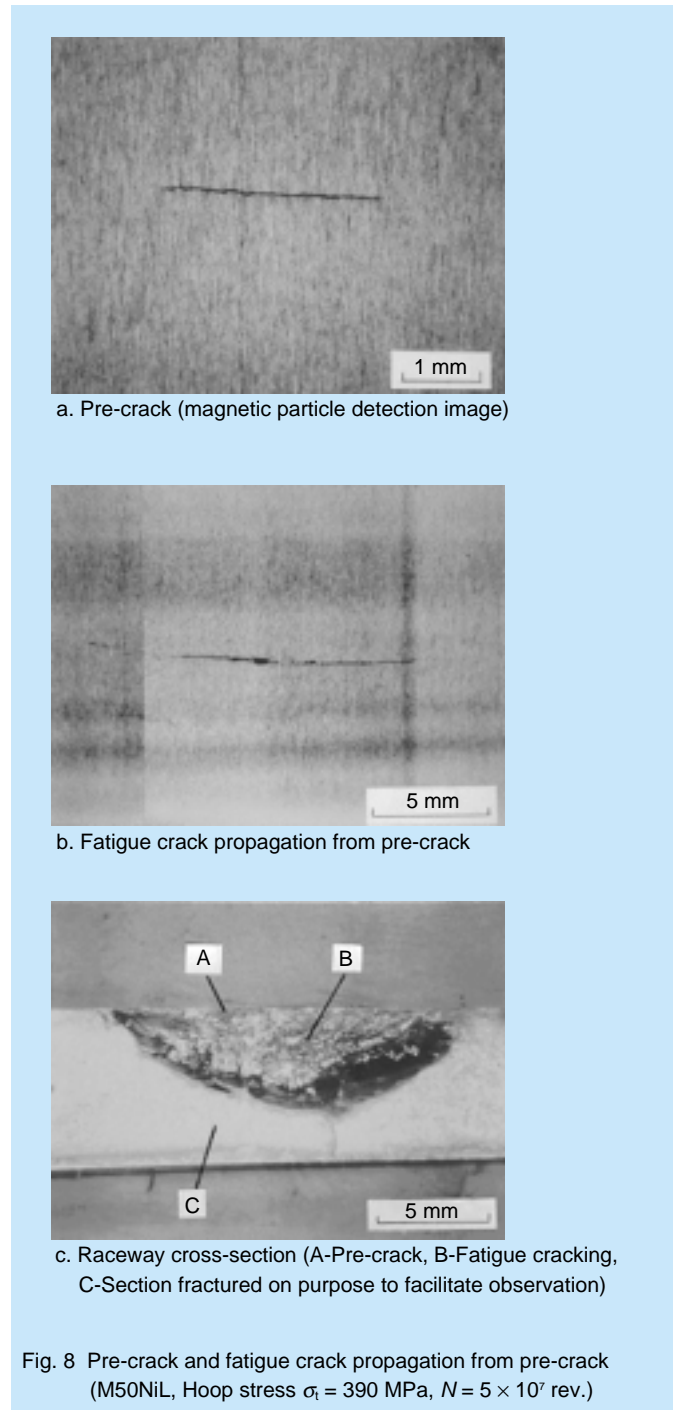
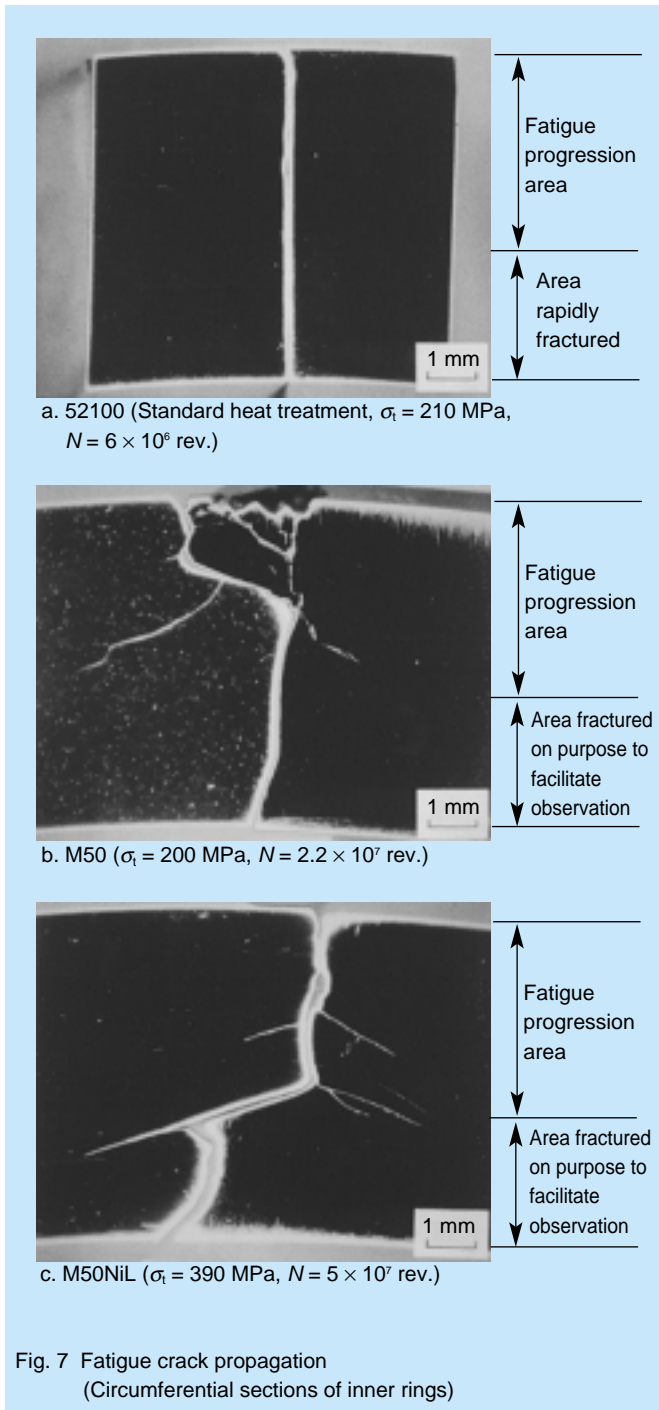


Fig. 6 Pre-crack and fatigue crack propagation from pre-crack (M50, Hoop stress  $\sigma_t = 200$  MPa,  $N = 2.2 \times 10^7$  rev.)



its long inner ring fracture life.

### 3.4 Inner ring fracture life and rolling contact fatigue life of TL bearings

NSK's new TL bearings are made of special case-hardened steel and undergo carbo-nitriding. (TL stands for Tough and Long-life.) Their compressive residual stress is equivalent to conventional carburized steel bearings and they have higher raceway hardness than high-temperature-tempered 52100 bearings or conventional carburized steel bearings. As shown in Fig. 4, the inner ring fracture life of TL bearings is on the same level as M50NiL and carburized steel.

In rolling contact fatigue (flaking) life tests, TL bearings showed exceptionally long life under conditions of contaminated lubrication at high temperatures due to the high hardness of their raceways (see the Weibull plotting of test results in Fig. 9).

### 3.5 Results of inner ring fracture life tests without pre-cracks

We have already discussed the influence of heat treatment, material, and hoop stress on the fracture life of inner rings with pre-cracks. Next, considering inner ring fracture in actual applications, we review tests done on inner rings without pre-cracks and present analyses of the

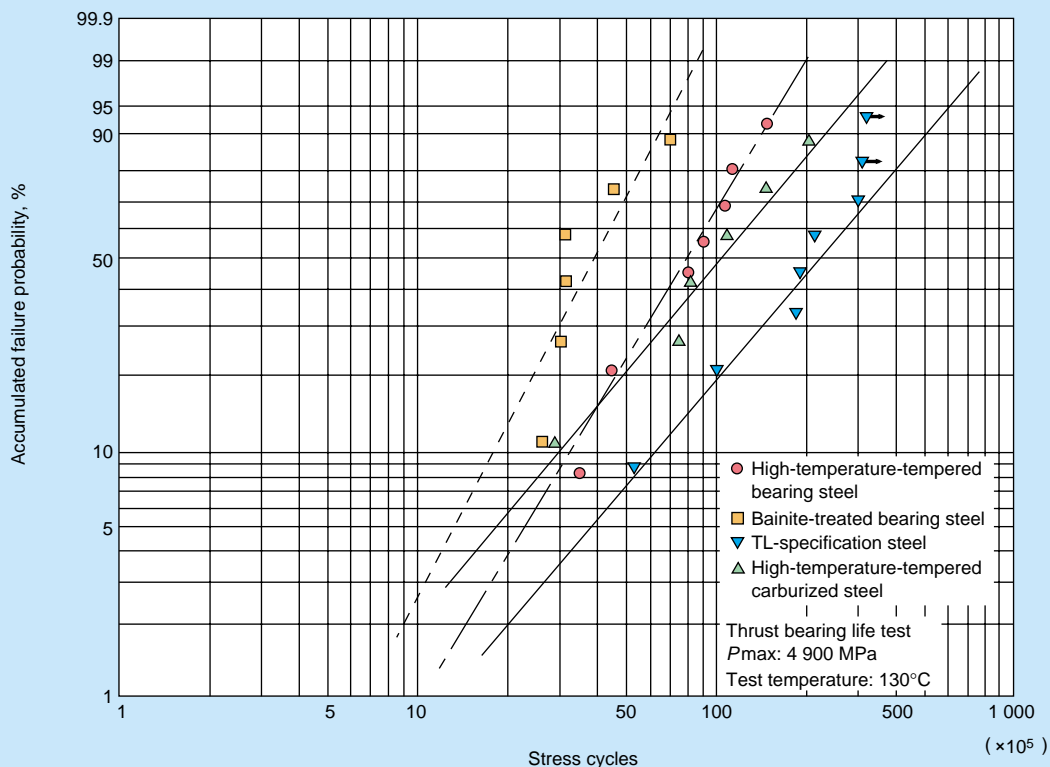


Fig. 9 Rolling contact fatigue test under high temperature and contaminated oil

origin points of fractures and the effect of hoop stress on fracture life. Tests were conducted on standard heat-treated 52100, bainite-treated 52100 and TL bearings. The test results are shown in Fig. 4.

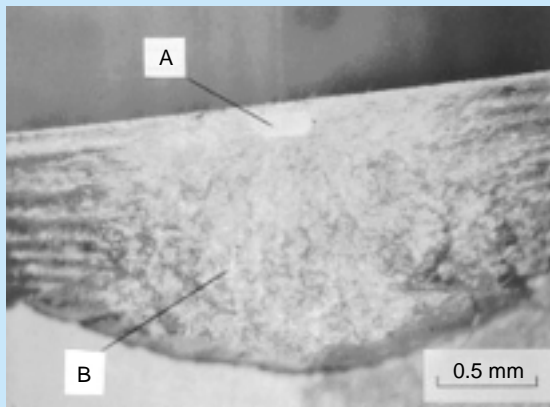
The standard heat-treated 52100 inner ring fractured at  $N = 1.2 \times 10^8$  revolutions under hoop stress of 280 MPa. The fracture surface is shown in Fig. 10-a. The origin point of the fracture can be seen near the raceway surface. Fig. 10-b is a magnified image of the fracture origin point. Fig. 10-c is a further magnification of the origin point showing a nonmetallic inclusion site. Located about 40  $\mu\text{m}$  below the raceway surface, the concave section can be seen running almost parallel to the raceway surface. The elements Mn, Ca, and S were detected in this concave area by EDS analysis (Fig. 10-d). It was concluded that the inner ring fracture occurred due to the presence of CaS inclusions. Also, an  $\text{Al}_2\text{O}_3$  and CaS inclusion site was determined to be the fracture origin point in a test under hoop stress of 230 MPa, and a CaS inclusion was the fracture origin point in a test under hoop stress of 400 MPa. As for the bainite-treated 52100 inner rings, fractures occurred at  $\text{Al}_2\text{O}_3$  and CaS inclusions under hoop stress ranging from 380 to 410 MPa. In contrast, TL steel inner rings did not fracture under hoop stress as high as 420 MPa. Fractures did finally occur at  $\text{Al}_2\text{O}_3$  inclusion sites under hoop stress ranging from 470 to 490 MPa. To summarize, inner ring fracture occurred at  $\text{Al}_2\text{O}_3$  and CaS inclusion sites in tests without pre-cracks.

#### 4. Residual Stress and Fracture Life of Inner Rings

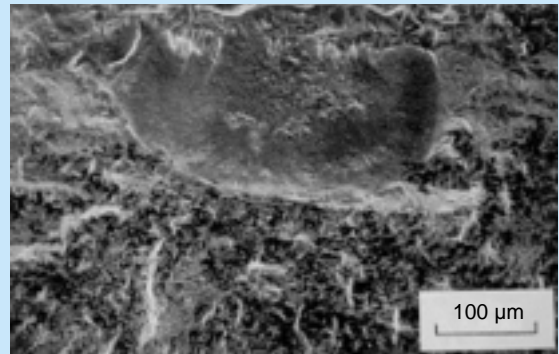
Fig. 11 shows measurement results on residual stress ( $\sigma_R$ ). Residual stress measurements were made on untested inner rings that received the same heat treatments as the tested inner rings.

Fig. 11 shows that the residual stress at the surface of the inner rings ranges from -300 to -500 MPa. This level of stress is attributed to the grinding process. The residual stress approximately 0.5 mm below the surface of both standard heat-treated and high-temperature-tempered 52100 inner rings is approximately 0 ~ +20 MPa. At the same approximate depth, the residual stress values for the other inner rings in the tests are as follows: bainite-treated 52100, approximately -120 MPa; TL specification, approximately -240 MPa; and M50NiL, approximately -280 MPa.

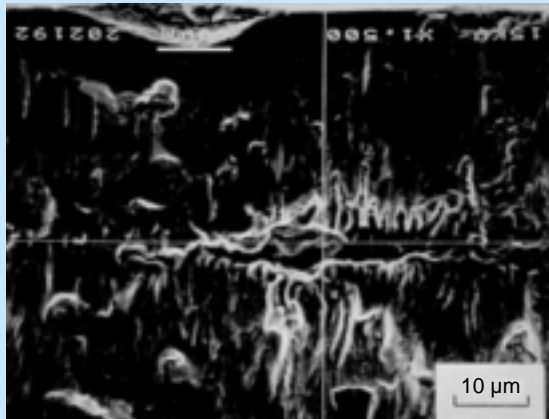
Comparing the inner ring fracture life test results in Fig. 4 to the residual stress values in Fig. 11, inner ring fracture life becomes longer as compressive residual stress increases. In the tests, the standard heat-treated 52100 inner ring fractured at about  $N = 1 \times 10^7$  revolutions under hoop stress of 400 MPa and at about  $N = 3 \times 10^8$  revolutions under hoop stress of 240 MPa. A bainite-treated 52100 inner ring fractured under hoop stress of 380 MPa at about  $N = 7 \times 10^7$  revolutions. In contrast, another bainite-treated 52100 inner ring under hoop stress of 350 MPa and the TL specification inner ring



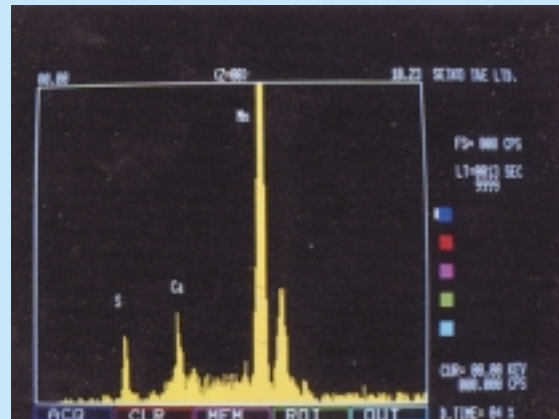
a. Fracture surface (A-Origin point of fracture, B-Fatigue cracking)



b. Magnified image of fracture origin point



c. Nonmetallic inclusion site at crack origin



d. EDS analysis of chemical composition of nonmetallic inclusions at crack origin

Fig. 10 Example of inner ring fracture test result without pre-crack (fatigue crack propagated from nonmetallic inclusions) (52100, Hoop stress  $\sigma_t = 280$  MPa,  $N = 1.3 \times 10^8$  rev.)

under hoop stress of 430 MPa did not fracture even after  $N = 3 \times 10^8$  revolutions.

From the results on inner ring fracture without pre-

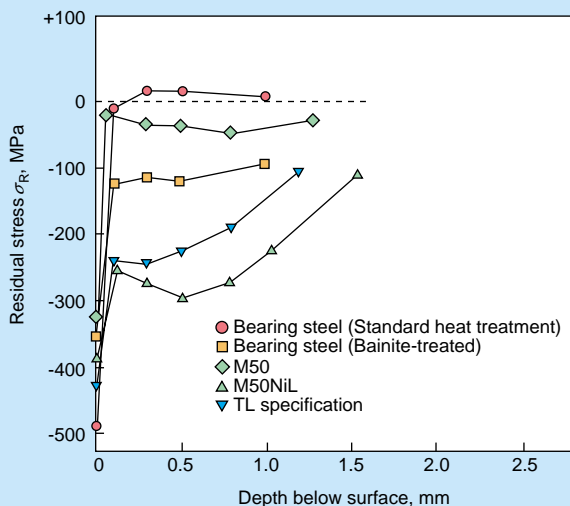


Fig. 11 Results of residual stress measurements

cracks, the importance of compressive residual stress is clear. There is a distinct tendency for inner rings with higher compressive residual stress to have longer fracture life when fractures originated from nonmetallic inclusions. We believe the correlation is strong enough to support the conclusion that higher compressive residual stress prolongs inner ring fracture life.

## 5. Conclusion

- (1) Inner ring fracture life correlates well with compressive residual stress. Compressive residual stress is effective in extending inner ring fracture life. In particular, it was shown that a fatigue crack propagates negligibly in an M50NiL inner ring with a pre-crack under 280 MPa hoop stress. The residual stress of M50NiL is approximately -280 MPa.
- (2) In the tests on inner rings without pre-cracks (results in Fig. 4), the standard heat-treated 52100 inner ring (residual stress approximately 0 ~ +20 MPa) fractured

---

under hoop stress of 400 MPa after about  $N = 1 \times 10^7$  revolutions, and the bainite-treated 52100 inner ring (residual stress approximately -120 MPa) fractured under approximately the same hoop stress after at about  $N = 7 \times 10^7$  revolutions. In contrast, the TL inner ring (residual stress approximately -240 MPa) did not fracture under hoop stress of 430 MPa after about  $N = 3 \times 10^8$  revolutions.

(3) The origin points of the inner ring fractures in the tests without pre-cracks were nonmetallic inclusions such as  $Al_2O_3$  and CaS.

(4) TL-specification bearings with higher raceway surface hardness showed longer rolling contact fatigue life under high temperature and contaminated oil.

### References:

- 1) B. L. Aberbach, et al, "Fatigue Crack Propagation in Carburized High Alloy Bearing Steels," Metal. Trans., A 16A (1985) 1253-1265.
- 2) J. C. Clark, "Fracture Tough Bearing for High Stress Applications," AIAA-85-1138 AIAA/SAE/ASME/ASEE 21st Joint Propulsion Conference July 8 -10 (1985).
- 3) P. K. Pearson, "Fracture and Fatigue of High Hardness Bearing Steels under Low Tensile Stresses," SAE Technical Paper 901628, International Off-Highway and Exposition, Milwaukee, September 10-13 (1990).
- 4) T. Czynzski, "Influence of a Tension Stress Field Introduced in the Elastohydrodynamic Contact Zone on Rolling Contact Fatigue," Wear, 34 (1975) 201-214.



*Kiyoshi Hirakawa*



*Norifumi Ikeda*



*Shigeru Okita*



*Akihiro Kiuchi*

# ABS Motor/Actuator Bearing Development for Applications Which Require Brake Fluid Compatible Contact Seals

Gary G. Chatell  
American Technical Center, NSK Corporation

## ABSTRACT

NSK has developed a brake fluid compatible bearing for use in ABS motor and actuator applications which require high-performance contact seals. This paper reports how NSK developed the necessary processes to accommodate EPDM seals on a mass production scale.

## 1. Introduction

ABS motors and actuators are typically designed with one or more single-row ball bearings that may come into contact with brake fluid. In applications requiring high performance contact seals, a brake fluid compatible seal material must be selected. For these types of applications, ethylene-propylene-diene-monomer (EPDM) material is normally chosen. This presents a challenge for bearing manufacturers due to the fact that EPDM material is not compatible with the mineral-based materials typically used in solvents, rust-preventative oils (RP oils), and greases. This paper describes how NSK developed the proper processes and materials to accommodate EPDM seals on a mass production scale.



Photo 1 ABS motor: Continental Teves

## 2. Design Challenges

1. Rust-preventative oil compatibility
  - with seal
  - with polyamide cage
  - with grease
  - with packaging
2. Grease compatibility

- with seal
- with brake fluid

3. Rust prevention capability
4. Seal noise prevention

### 2.1 RP oil compatibility

The vast majority of bearing RP oils are mineral oil based, which can cause extreme swelling and distortion of EPDM material. Therefore, NSK co-developed (along with our supplier) a polyglycol-based RP oil that is compatible with EPDM material. A detailed research plan was developed to determine the optimum RP oil viscosity. The interrelated properties to consider were rust prevention capability (oil film thickness), filterability (use in mass production), and seal lip lubrication (prevention of seal noise). The relationship between these properties is illustrated in Fig. 1.

#### 2.1.1 RP oil to seal compatibility

The EPDM seals were submerged in the polyglycol-based RP oil at 40°C. Volume and weight changes, along with visual appearance, were recorded at 100-hour intervals up to 500 hours. At the conclusion of the test, changes in both weight and volume were less than 2%. There was no visible change in appearance.

#### 2.1.2 RP oil to plastic cage compatibility

Swelling and distortion of the cage would be detrimental to bearing life. Therefore, the cage was subjected to the same test conditions as the seal above. Changes in both weight and volume were less than 0.5%.

#### 2.1.3 RP oil to grease compatibility

Incompatibility can cause grease leakage and result in insufficient lubrication. Three different types of grease were mixed with the RP oil (90% grease; 10% RP oil) and the changes in consistency were recorded immediately and after 24 hours (Fig. 2). The following base oil/thickener combinations were tested:

- fluoroether/PTFE
- polyolester/diurea

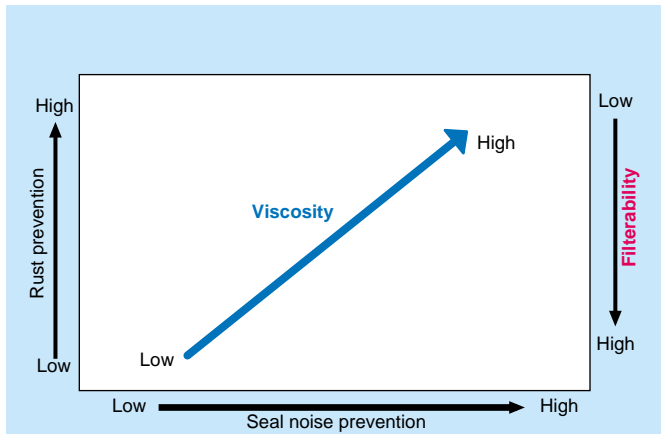


Fig. 1 Relationship between oil viscosity and filterability

- synthetic hydrocarbon/lithium complex

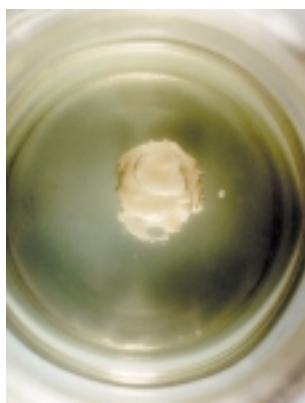
As expected the fluorinated grease exhibited very little change in consistency. The polyolester sample exhibited an initial change, but remained consistent over the next 24 hours. The consistency of the synthetic sample increased greatly initially and continued to increase over time. The fluoroether and polyolester samples also performed well during subsequent grease purge testing.

#### 2.1.4 RP oil to packaging compatibility

Typically, volatile corrosion inhibitor (VCI) type packing material is used in the bearing industry to prevent corrosion (rust) during shipment and storage. Plastic bags and tubes are also used. Incompatibility could cause a breakdown in the packaging resulting in corrosion and/or material handling problems. The packing materials were half submerged in the polyglycol-based RP oil for a period of 30 days at 40°C. There was no physical difference in the materials at the conclusion of the test.

### 2.2 Grease compatibility

Normal mineral oil-based grease is not compatible with EPDM seal material or brake fluid. If grease easily breaks down due to contact with brake fluid, grease leakage and/or insufficient lubrication can result and bearing life will be dramatically reduced.



Fluorinated grease



Polyolester grease

Photo 2 Grease submerged in brake fluid for a period of 72 hours

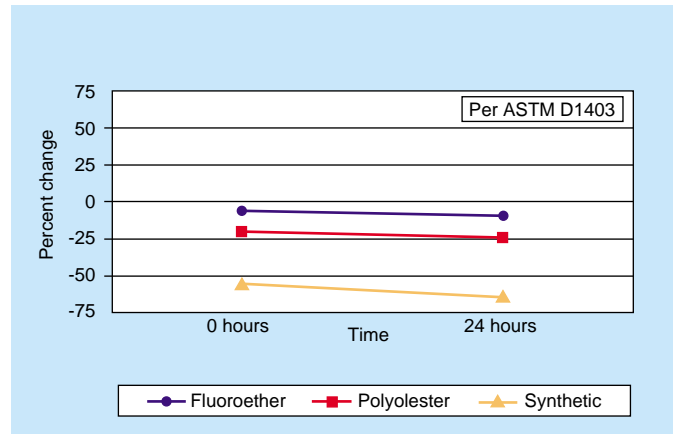


Fig. 2 Change in grease consistency after mixture with 10% RP oil

#### 2.2.1 Grease to seal compatibility

For optimum compatibility between the grease and EPDM seal material, a fluorinated grease should be specified. Fluorinated greases are nearly inert and do not react with EPDM. However, due to the cost associated with fluorinated greases, other less compatible greases are sometimes used. Care should be exercised when this is done. Some seal swelling will occur, but the amount of swelling and subsequent reduction in sealing capability may not be large enough to cause performance problems in the application. The interaction of these less compatible greases should be studied through extensive testing before being designed into the bearing.

#### 2.2.2 Grease to brake fluid compatibility

As typical brake fluid and the polyglycol-based RP oil are very similar chemically, compatibility test results would be expected to be very similar to those shown in Fig. 2. The fluorinated grease is expected to show very little effect from contact with brake fluid. This expectation was confirmed in testing and can be seen in Photo 2. Both fluorinated and polyolester greases were submerged in brake fluid for a period of 72 hours. Photo 2 shows that the fluorinated grease remains intact while the polyolester grease begins to dissolve. Therefore, in applications where brake fluid intrusion is likely, the use of a fluorinated grease is recommended. If contact with brake fluid is highly unlikely, an alternative, less costly grease may be used after proper validation testing.

Table 1 Rust preventability (per ASTM D1748)

RP oil type	Film thickness (µm)	Duration		
		100h	250h	500h
Polyglycol-based oil	0.4	A	A	B*
	0.7	A	A	A-B*
	1.4	A	A	A-B*
	2.2	A	A	A
	3.2	A	A	A
	4.0	A	A	A
Mineral oil	0.6	A	A	A

\*All of the rust found was external to the bearing seals. No rust was found inside the bearing.

A=no rust B=1-10% rust

Table 2 Seal noise prevention capability comparison

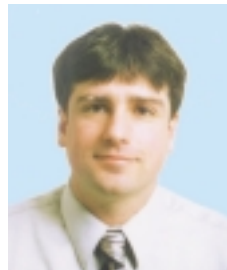
Sample Group	Sample Size	Initial Noise Level	After 5 min	After 1 hr	After 3 hrs	After 10 hrs	After 20 hrs
Polyglycol-based RP oil	16	16 Q	16 Q	16 Q	15 Q 1 SL	15 Q 1 N	15 Q 1 N
Brake fluid	8	8 Q	8 Q	8 Q	8 Q	7 Q 1N	5 Q 2 SL 1N

Q=quiet SL=slightly noisy N=noisy

### 2.3 Rust prevention capability

The goal in developing the polyglycol-based RP oil was to have rust prevention capabilities as close as possible to standard mineral oil-based RP oils. We quickly realized through testing that we would not be able to match the salt spray rust-preventing capability of standard mineral oil-based RP oils. Based on the fact that most ABS motors are enclosed, we determined that the main purpose of the RP oil should be to protect the bearing during transportation and storage. In any case, the RP oil would provide significant protection compared to shipping the bearings dry, which is the only alternative when using EPDM seals. Testing was conducted in accordance with ASTM D1748 to determine the rust-preventing capability of the polyglycol-based RP oil at different film thicknesses. The results are shown in Table 1. Please note that all of the corrosion found was external to the bearing seals. No corrosion was found inside the bearings.

option. Through strenuous testing and much development work done in conjunction with our supplier, NSK has developed an ABS motor/actuator bearing that is completely brake fluid compatible. The design has been in mass production now for four years. For further information, please contact your NSK sales or engineering representative.



Gary G. Chatell

### 2.4 Seal noise prevention

Seal noise can occur due to sliding friction (stick-slip) between the seal contact lip and the bearing seal groove. This phenomenon is very similar to that of a windshield wiper operating on a dry windshield (windshield wiper blades are typically made from EPDM material). To eliminate this seal noise, some users have taken the time-consuming approach of applying brake fluid to the seal lip. After applying brake fluid, there has not been an occurrence of seal noise. Therefore, when developing the new polyglycol RP oil, NSK decided that the seal noise prevention ability of the new RP oil should be at least equivalent to that of brake fluid.

NSK compared the seal noise prevention capability of the polyglycol RP oil to that of brake fluid by rotating bearings at 3 600 rpm and checking for seal noise at various time intervals. The results are shown above in Table 2. Considering that brake fluid is known to prevent seal noise and that the test results show the polyglycol RP oil to be superior to brake fluid in this respect, NSK is confident that the polyglycol RP oil will prevent seal noise when sufficient quantities are applied to the bearing.

## 3. Conclusion

When applications require brake fluid compatible contact seals, the EPDM seal and polyglycol-based RP oil combination has been shown to be a viable, cost-effective

# High-Performance Ball Bearings for Fan Motors in the Chinese Market

*Keiichi Yasuhara, Kunshan Plant, China  
Pu Jiami, China Technical Center*

## 1. Introduction

Although most countries in Asia have been mired in economic slumps in recent years, China has been experiencing steady economic growth of several percent per year in GNP as a result of its economic liberation policies. The household electrical appliance industry in China has been no exception, showing no signs of a slowdown in sales growth. Newly established manufacturers, including foreign-affiliated companies, are competing intensely in the booming market. Recognizing that product quality is the key to survival, each year they have been requiring bearings with more functions and higher reliability.

Bearings for household electrical appliance motors are a very important market for NSK. Household electrical appliance motors mainly include air conditioner fan motors, range hood fan motors, washing machine motors, vacuum cleaner motors and ceiling fan motors. In line with appliance manufacturers' increasingly stringent requirements, motor manufacturers demand bearings of higher quality and performance. This paper focuses on bearings for fan motors, which, among bearings for the aforementioned types of motors, must exhibit especially high performance. Current requirements in the Chinese market will be discussed along with NSK's response in terms of product technology and production methods.

## 2. Fan Motor Market

An estimated 10 to 15 million fan motors are produced per year in China for household electrical appliances. Worldwide air conditioner fan motor consumption is approximately 23 million per year and 30 to 40 percent of these motors (approximately 7 - 9 million) are produced in China. There are five leading air conditioner manufacturers in China and, reflecting the intense competition in the industry, each of the five has held the top position in the market in recent years. Regionally, sales of air conditioners are particularly high in eastern and southern China. With all of the air conditioner manufacturers exporting their products, China is an important player in the world air conditioner market.

There are numerous fan motor manufacturers in China and many are affiliated with Chinese, Japanese, American or European air conditioner manufacturers for reasons of product quality, local base and/or financial connections. The competition among the fan motor makers is severe. Generally speaking, Japanese-affiliated companies excel in



Photo 1 Kunshan Plant

product quality, while local independent companies have the edge in costs.

## 3. Special Circumstances of Fan Motor Bearings in China

608, 6200, 6201 and 6202 bearings with inside diameters ranging from 8 to 15 mm are the main bearings used in fan motors. Special characteristics of the fan motor industry in China include:

### ■ Noise inspections

Fan motors delivered to appliance manufacturers are thoroughly inspected for noise before being accepted. This practice is undertaken to ferret out counterfeit products, a not so uncommon problem in China, and is made possible by the abundance of inexpensive labor. Inspections at the appliance manufacturers are carried out manually—inspectors apply their ears directly to running motors to assess noise level. Noise, even if otherwise inaudible under

the dominating hum of the running fan, can thus be detected. When a motor's noise level is determined to be unacceptably high, the motor manufacturer is penalized. Generally, motor manufacturers have their own inspection shops located near appliance manufacturers' plants. They inspect 100% of their motors using the same criteria as appliance manufacturers and ship only those that are approved.

To help ensure meeting the requirements of air conditioner manufacturers and also to detect counterfeit products, motor manufacturers carry out noise inspections on the bearings they receive, applying strict standards. These standards are made especially exacting by the perception that even slightly unusual bearing noise indicates a defective bearing. Thus, fan motor bearings must generate very little raceway noise and be free of any irregular noise.

### ■ Transportation problems

Motors are often shipped hundreds of kilometers to air conditioner manufacturers. During this time, rugged roads and the limited shock resistance of the trucks in which the motors are shipped can result in fretting of the outer and inner raceways of the bearings inside the motors. This fretting causes unusual noise that may be perceived to indicate defects. For this reason, even motors deemed acceptable in terms of noise before shipment can be rejected when they are inspected by air conditioner manufacturers. Bearings, therefore, must have high resistance to fretting.

### ■ Fitting methods

In China, bearings are often fit on motor shafts

manually. Assembly workers, using their own weight, press fit housings onto bearings and use mallets to align pairs of upper and lower housings. Both of these practices can apply excessive loads to bearings and result in damage and noise. For this reason, bearings that are less likely to be damaged by such assembly practices are recommended. Bearings with an inside diameter of 8 mm are especially susceptible to such damage and therefore special care should be taken.

### ■ Motor varnishing practices

Varnish-related bearing corrosion is another problem that may arise at certain motor manufacturers. This occurs when varnish applied to motors is not allowed to fully dry before the motors are stored in the hot and humid atmosphere of summer.

Market research carried out by the NSK Bearing Technical Center in China on the aforementioned motor and bearing problems indicated that assembly-related problems, including damage caused during assembly, accounted for 23%, fretting 19%, corrosion 8%, noise 33%, and other factors 17%. The functions required for fan motor bearings in response to the circumstances described above are summarized in Fig. 1.

## 4. Functional Improvement and Production of Fan Motor Bearings

### 4.1 Improvement in noise performance

In response to the strict noise inspections of fan motors noted above, NSK improved the noise performance of its fan motor bearings. We reduced bearing noise by

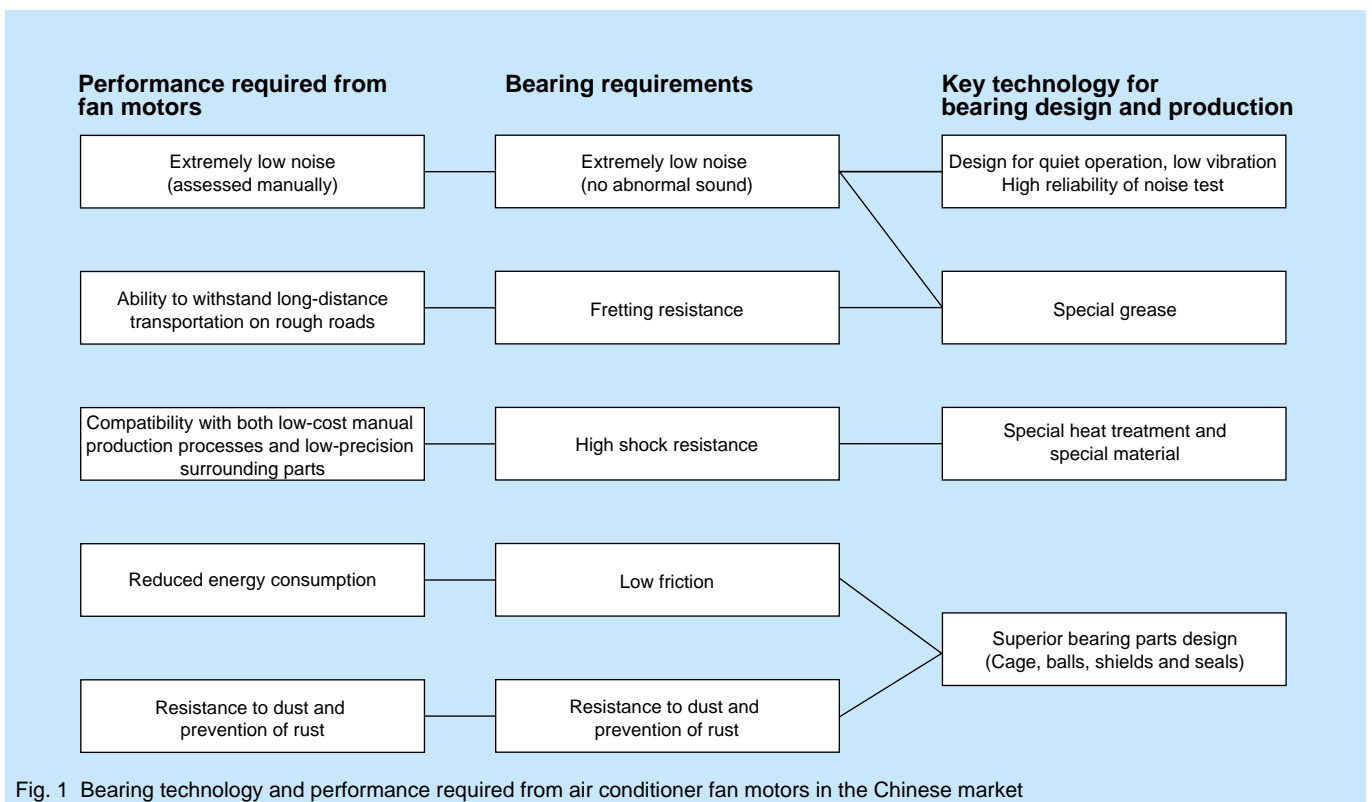


Fig. 1 Bearing technology and performance required from air conditioner fan motors in the Chinese market

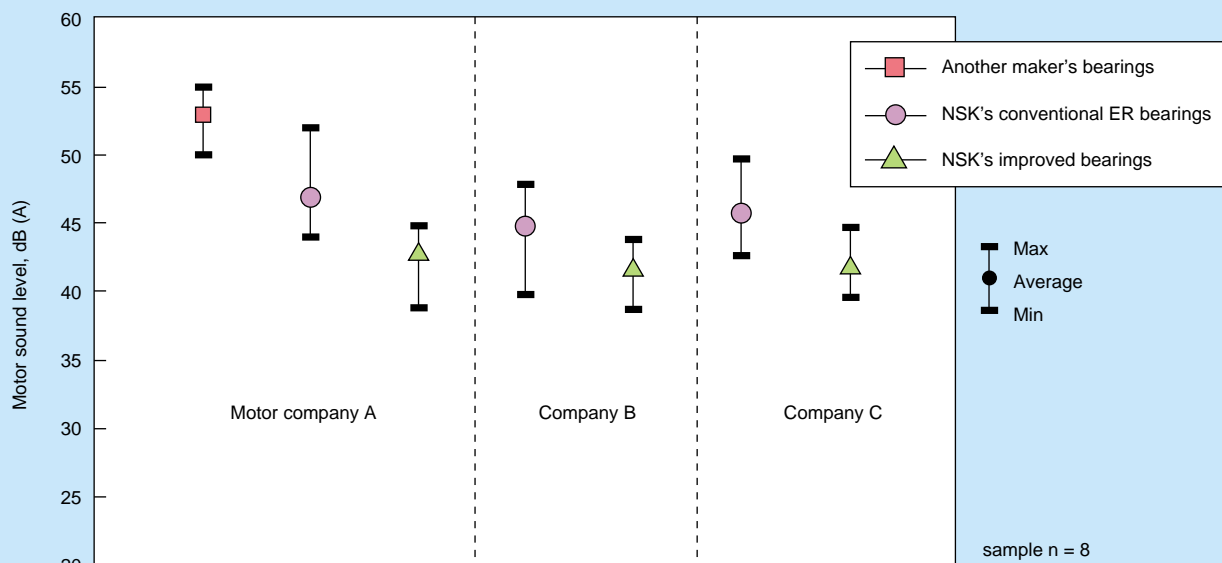


Fig. 2 Comparison of the sound level of motors with quiet bearings

improving grinding, assembly and washing techniques. NSK established a mass production system for the new bearings at the Kunshan Plant (Photo 1). Fig. 2 shows test results on the new bearing. The noise level of motors containing this bearing was reduced by 2 to 3 dB.

#### 4.2 Improvement in fretting and shock resistance

Fretting of bearings tends to occur when the motors are transported on trucks. The relationship between the occurrence of fretting and grease viscosity is illustrated in Fig. 3. For fan motor bearings, a lithium soap grease is generally used because of its low-noise performance. For fan motor bearings that are to be transported in rough conditions, NSC grease shows higher fretting resistance than NS7 grease, which has lower viscosity. NSA grease, with higher viscosity than NSC, exhibits still higher fretting resistance. Therefore, the use of grease with high viscosity is considered to be effective in reducing the likelihood of fretting.

Paradoxically, cage noise from balls colliding with the

cage is more likely to occur when high-viscosity grease is used. For fan motor bearings in China, pressed cages are mainly used. In response, NSK reviewed the design of the pressed cage for the Chinese market and improved it to minimize cage noise. The Kunshan Plant has recently started up new assembly lines for the improved cages for fan motor bearings 6200 to 6202.

Bearings with improved shock resistance can be produced at the Kunshan Plant. Fig. 4 compares axial-direction vibration of conventional and improved 608 bearings. The axial vibration of improved 608 bearings remains much lower than the conventional bearings, even if the axial load increases.

#### 4.3 Evaluation in the Chinese market

Samples of the quiet bearings produced at the Kunshan Plant were submitted to three leading air conditioner manufacturers in China for evaluation by their affiliated motor manufacturers. In the evaluation, the quality of the bearings was determined to be higher than that of conventional bearings. Consequently, the improved

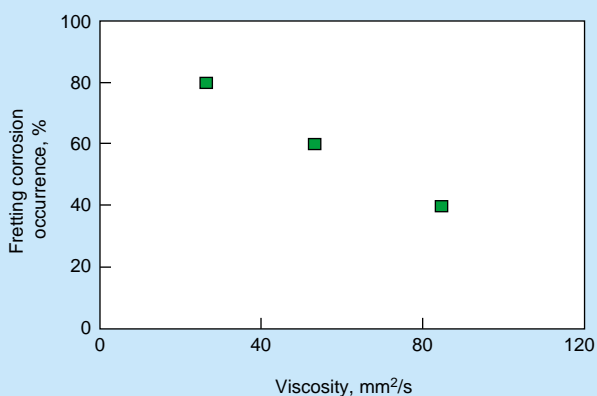


Fig. 3 Effects of base oil viscosity on fretting corrosion

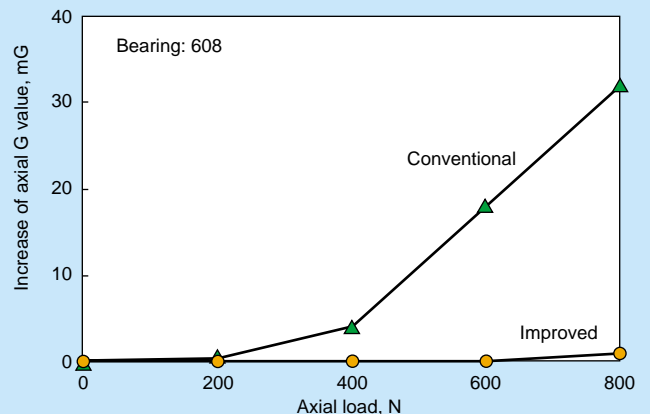


Fig. 4 Improvement of shock resistance

---

bearings from the Kunshan Plant have replaced the imported Japanese bearings.

In China, many bearing users, including motor manufacturers, have only recently started production. Many have encountered problems related to bearing fitting, preload, rust and other factors in their production efforts. The NSK Bearing Technical Center in China has been working hard to provide prompt technical support and solutions when such problems arise. The support services have been widely appreciated by users.

## 5. Conclusion

The household appliance industry in China has been growing rapidly, and the bearings used by the industry are required to meet strict performance standards. The Kunshan Plant has been mass-producing bearings that meet these exacting requirements. Nevertheless, requirements for bearings with even higher performance at lower cost are expected in the future. The Kunshan Plant and the NSK Bearing Technical Center in China will make every effort to develop and supply such products in a timely and efficient manner.



*Keiichi Yasuhara*



*Pu Jiami*

# SNN Series Plummer Blocks

Plummer blocks, which are classified as medium to large bearing units, are widely used in industrial machinery and material-handling equipment because of their ease of use.

Today, reducing labor and maintenance costs is a primary objective throughout industry. In response, NSK applied its considerable technologies and experience to develop SNN Series Plummer Blocks (Photo 1), high-performance bearing units that are even easier to handle than the previous SN Series. SNN Series Plummer Blocks have the following features (refer to Photo 2):



Photo 1 SNN Series Plummer Blocks

## ■ Seal variety

The most appropriate seals for a given operating environment can be selected from among various seal types (Table 1).

## ■ Longer bearing life

A gap provided between the rib under the bearing seat and the mounting surface widens the distribution of the load within the bearing and extends bearing life.

## ■ Highly rigid housing

Reinforced structure prevents deformation of the bearing seat for high rigidity.

## ■ Shared use of plummer block housings

Bearings of different dimensional series but with the same outside diameter can be mounted in the same plummer block housing.

## ■ Holes for lubrication

A threaded hole for oil or grease is provided on top of the unit. Depending on bearing and seal specifications, additional holes can be drilled at the provided dimples.

## ■ Large oil bath

The large oil bath can store an ample quantity of lubricant and thereby help maintain stable lubricating

conditions and extend the oil change interval.

## ■ Heat dissipation

Bearing heat dissipates quickly through the heat transfer webs on the bottom of the unit. As a result, lubricant remains effective for longer periods of time.

## ■ Free surface on face

The large flat face of the unit can be used for oil drain holes, oil level gauges and/or sensors.

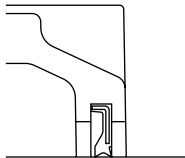
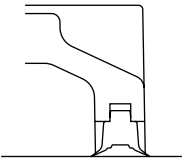
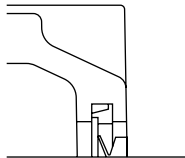
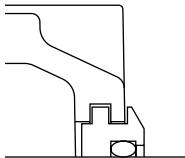
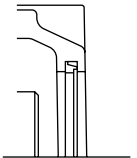
## ■ Dimples for mounting bolts

Four dimples are provided for additional mounting holes if the existing holes do not correspond with specific mounting requirements.

## ■ Dimples for positioning pins

The dimples at the four corners of the unit's base can be used to enable positioning with pins.

Table 1 Seal types and their features

Seal type					
	Contact			Non-contact	—
	U-LOK Seal	G-LOK Seal	V-RING Seal	TS-RING Seal	End Cover
Maximum speed	4 m/s	5 m/s	7 m/s	Bearing's limiting speed	—
Grease lubrication	Excellent	Excellent	Excellent	Good	—
Oil lubrication	Fair	Fair	Good	Excellent	—
Friction torque	Good	Good	Good	Excellent	—
Temperature range	-20 ~ +80°C	-20 ~ +80°C	-20 ~ +80°C	-20 ~ +120°C	-20 ~ +120°C
Performance when exposed to	Dust	Excellent	Excellent	Good	—
	Large particles	Good	Good	Good	—
	Water	Good	Good	Good	Poor

■ **Easy handling**

*Center marks*

Recesses indicating the housing center are provided at four points. These are very helpful when centering the unit during mounting.

*Rectangular base*

The base of the unit is rectangular to facilitate alignment during mounting.

*Prevention of mismatching*

The upper and lower halves are marked to prevent mismatching.

*Notches for separation*

Four notches are provided in the mating area of the upper and lower halves to facilitate separation with a screwdriver.

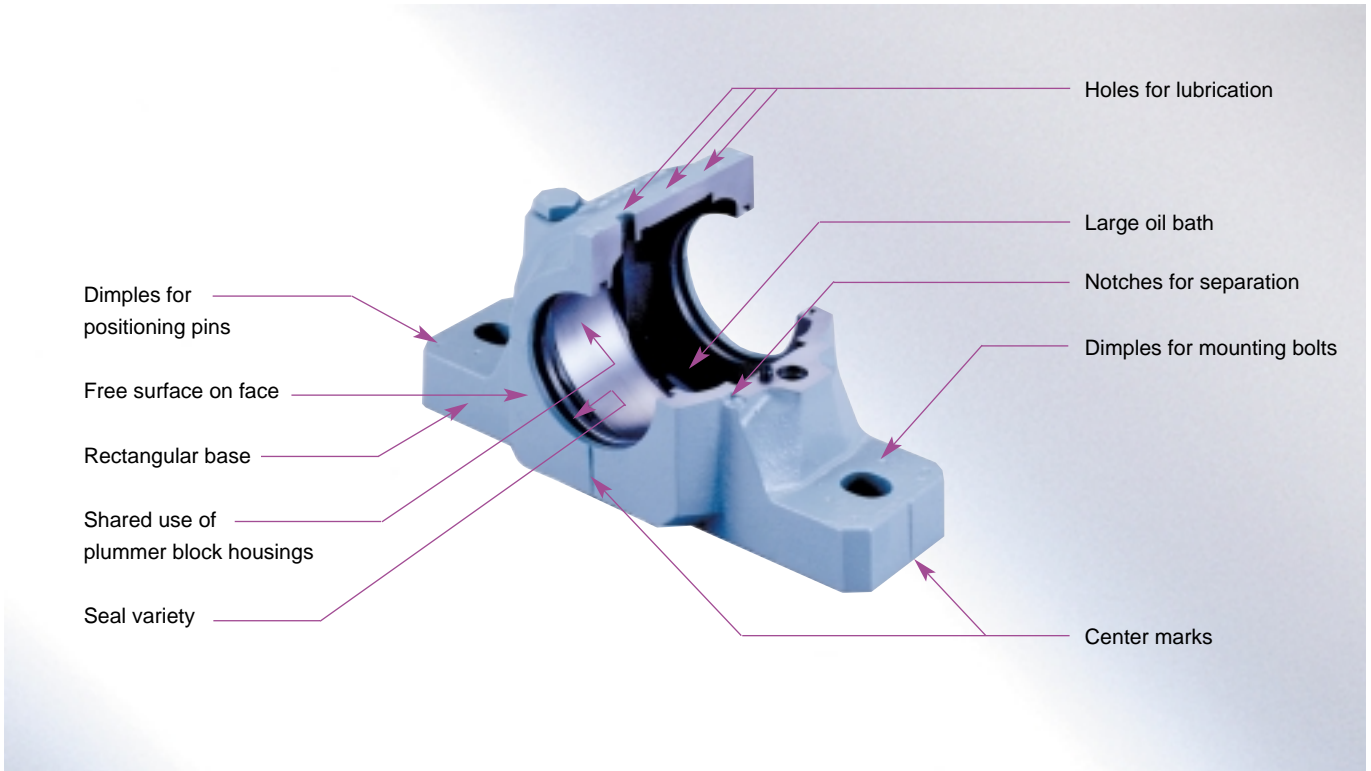


Photo 2 Features of SNN Series Plummer Blocks

# RMA and RMS Series of Precision Rolled Miniature Ball Screws

NSK developed its MA and MS series of miniature ball screws (JIS C3 Class) in response to the trend toward smaller and lighter machinery and equipment. To meet customer requirements for lower prices and faster delivery, NSK recently developed a method of manufacturing precision rolling ball screws that eliminates the grinding process. Utilizing this technology, NSK created the RMA and RMS Series of low-price miniature ball screws (JIS Ct7 Class). The new series provide outstanding solutions for various applications, including small actuators and material-handling systems. We are pleased to present them in this article.

## Features

### ■ Low price and quick delivery

The precision rolling method employed in producing the shafts reduces costs by eliminating the grinding process. Both series of ball screws are maintained in well-stocked inventories for prompt delivery.

### ■ Interchangeability with existing ball screws

Replacement is easy because outside diameters are interchangeable with existing miniature MA and MS Series ball screws.

### ■ Shaft end design

The fixed-side shaft end of the RMA Series is specially processed to enable immediate mounting on equipment using support kits or units. As for the RMS Series, the fixed-side shaft end can be easily machined to suit specific applications because it is not hardened or otherwise processed.

### ■ Availability of support kits and units

With a support kit, users can design compact devices with RMA Series ball screws (Photo 1).

## Specifications and Dimensions

### ■ Series composition

Shaft diameters range from 6 to 12 mm, and the available leads are 1, 1.5 and 2 mm. Six combinations are available. Like the MA and MS Series, the two series use a compact nut that employs deflectors in the circulation of the balls. Table 1 shows the standard dimensions of the new series.

### ■ Accuracy and axial play

Accuracy conforms to JIS Ct7 Class (JIS B1192). Axial play is less than 0.02 mm (S clearance). Collars are used in the bearing seats to ensure the mounting accuracy of the RMA Series.

### ■ Support kits and units

Though conventional support units use angular contact ball bearings, support kits for the RMA Series use two flanged bearings. They have no axial play and provide low-cost alternatives. Support kits and units are standard stock and can be supplied quickly. Table 2 lists the dimensions of the support kits for RMA06 and 08 (6-mm and 8-mm screw shaft diameters). With RMA10 and 12, conventional support units are used.



Photo 1 RMA Series Precision Rolled Miniature Ball Screws and Support Kits

Table 1 Dimensions of RMA and RMS Series

Units: mm

Screw shaft dia. d	Lead	Basic load rating, N		Ball nut dimensions						Shaft dimensions		Series
		Dynamic	Static	D	L	A	W	B	H	Total shaft length	Effective stroke	
6	1	520	925	12	15	24	18	3.5	16	160, 260	100, 200	RMA06
										300	210	RMS06
8	1	600	1290	14	16	27	21	4	18	180, 280	110, 210	RMA08
										300	220	RMS08
8	1.5	810	1590	15	22	28	22	4	19	180, 280	105, 205	RMA08
										300	215	RMS08
8	2	990	1770	16	26	29	23	4	20	180, 280	100, 200	RMA08
										300	210	RMS08
10	2	1210	2510	18	28	35	27	5	22	250, 350	150, 250	RMA10
										350	240	RMS10
12	2	1350	3190	20	28	37	29	5	24	250, 350	150, 250	RMA12
										350	240	RMS12

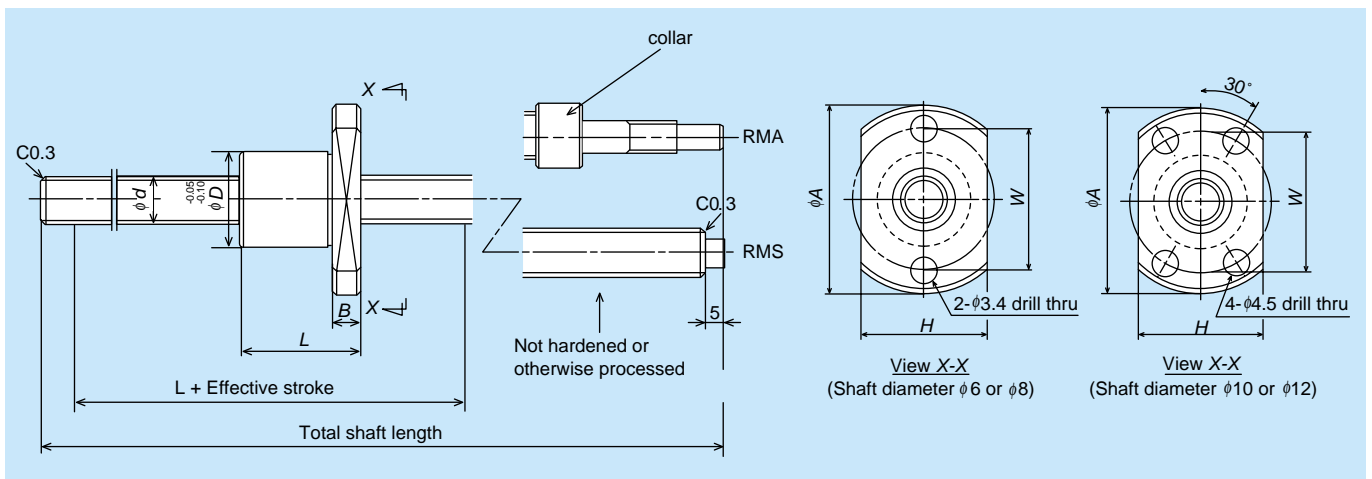


Table 2 Dimensions of support kits

Units: mm

Model No.	d	D	L	F	A	B	W	H	Applicable RMA Series
WBK04R-11	4	13	9	5	25	2.5	19	14	RMA06
WBK06R-11	6	18	11	6.8	30	2.5	24	19	RMA08

