Recent Technical Trends in Ball Screws

Mizuho Ninomiya and Kazuo Miyaguchi
Linear Motion Engineering Department,
Precision Machinery & Parts Technology Center

1. Introduction

Ball screws were first utilized as part of automotive steering systems by G.M. in the U.S. in the late 1930's. Twenty years later, the first ball screw was manufactured in Japan by NSK Ltd., and in 1961, NSK delivered its first precision ball screws for machine tools. Since then, as machine tools have become numerically controlled, ball screws have made great progress both in quality and production quantity. Applications for ball screws have been increasing due to their superiority over other linear motion-transmitting elements in terms of the balance between cost and performance, and their being widely recognized as easy to use and control.

In the mechatronics field for semiconductors, LCDs and robots in particular, demand for ball screws has grown to nearly equal that for ball screws used in machine tools. Additionally, demand for ball screws for special environment applications such as in aircraft, outer space and nuclear reactors is rising sharply. Considering this rising demand and broadening range of applications together with users' needs to continually improve their specific applications, the need for improved ball screw performance has no limit.

In this article, recently developed technologies for increasing the operational speed of ball screws and satisfying the diversifying needs of today's market are explained, and related new products are presented.

2. Response to Requirements for Higher Speed

The feed rate of NC machine tools, robots and electronic component-inserting machines has increased greatly in the past ten years, doubling and even tripling in some cases. Thus, the ball screws used in these machines have been and will continue to be required to achieve higher and higher speeds. Table 1 lists some examples of high-speed requirements.

The linear speed achieved by a ball screw is the product of screw lead and rotational speed. Next, we look into these two factors.

<table>
<thead>
<tr>
<th>Machine tools such as machining centers</th>
<th>General high-speed level</th>
<th>Highest speed level</th>
<th>Target speed level for the near future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robots, punching presses, etc.</td>
<td>60 ~ 80</td>
<td>~ 120</td>
<td>150 ~ 200</td>
</tr>
</tbody>
</table>

Table 1 High-speed requirements

units: m/min

In the past, ball screws were predominantly used for the speed-reducing function (2) and, in general, their leads were not so long. However, lengthening lead enables a higher feed rate with the same screw rotational speed. Therefore, in response to the need for ever-higher feed rates, there has been a tendency to increase lead length. In recent years, even in machine tools like machining centers, the use of ball screws with leads of around half of their screw shaft diameters, such as those in the HMC Series for high-speed machine tools, has increased. In addition to the HMC Series, NSK has developed several different series for robots and transporting equipment, applications in which function (3) is more important than functions (1) or (2). These include its:

- Triple Lead Series (Photo 1)
- Precision High Helix Lead/ Ultra High Helix Lead Series
- Rolled High Helix/ Ultra High Helix Lead Series
- Miniature High Helix Lead/ Ultra High Helix Lead Series

Triple Lead Series ball screws developed by NSK were
the first in the world to have leads almost three times the screw shaft diameter. In the Miniature High Helix Lead/Ultra High Helix Lead Series, we have successfully developed ball screws in the 8 to 12 mm-diameter range with very long leads previously thought difficult, if not impossible to attain.

In order to make high speed and high precision compatible, it is necessary to maintain a good balance between lead and rotational speed. Improvement of high-speed rotational performance is becoming increasingly important.

2.2 Improvement of high-speed rotational performance

Problems which need to be addressed in order to increase ball screw rotational speed include the following:

1. Limiting speed determined by \( d_m N \) (the revolving speed of the balls)
2. Limiting speed determined by the critical speed of the screw shaft
3. Increase in vibration and noise
4. Increase in temperature and thermal deformation
5. Increase in load caused by higher speed and higher acceleration/deceleration

Next, these problems and their countermeasures are explained, and related new products are presented.

2.2.1 Limiting speed determined by \( d_m N \)

When \( d_m N \) (\( d_m \) – ball pitch diameter in mm, \( N \) – rotational speed of screw in rpm; this represents the revolving speed of the balls) reaches certain levels, the repetitive shocks generated by the balls cause damage to the ball re-circulating mechanism and screw grooves. Therefore, the maximum speed of a ball screw is limited by this value. Fig. 1 illustrates the measuring method used to determine the force exerted on the tongue (pick-up finger) of a ball return tube. Measurement results are shown in Fig. 2. Force was generated by each ball entering the ball return tube; however, it was determined that nearly no force was generated when the balls exited the tube. Fig. 3 is a graph showing the proportional relationship between

![Fig. 1 Method used to measure impact force on ball return tube tongue](image1)

![Fig. 2 Measurement results of impact force on tongue](image2)

![Fig. 3 Rotational speed and impact force](image3)
ball speed and force magnitude. This supports the theory that the transfer of energy between the balls and the return tube tongue causes deformation of the tongue.

Fig. 4 shows data obtained through FEM (finite element method) analysis of the stress distribution when a ball collides with the return tube tongue. The data in this figure can be used to develop measures to strengthen the return tube tongue.

We are designing and manufacturing ball re-circulating mechanisms which can withstand increasing \( d_{\text{mN}} \) values by improving and strengthening the raw materials used in their production and determining the optimum shapes for the ball grooves and tongue of the ball return tube through the analysis of shock force measurements, FEM analysis and high-speed endurance tests.

The ordinary guaranteed \( d_{\text{mN}} \) value for ball screws has been 70,000, but we have developed and marketed ball screws with a guaranteed \( d_{\text{mN}} \) value of 150,000 through the application of the aforementioned methods, and have conducted high-speed tests exceeding 200,000 \( d_{\text{mN}} \) in our laboratory.

2.2.2 Limiting speed determined by the critical speed of the screw shaft

The maximum speed of a ball screw with a long stroke is governed predominantly by the critical speed of the shaft. As these kinds of ball screws have long and narrow shafts supported at both ends, great resonance occurs at high speeds when rotational speed reaches the natural frequency of the shaft. The speed at which this resonance occurs is called the critical speed of the shaft and the effects of this resonance include screw shaft vibration on the order of several millimeters which causes damage to the grooves as well as extreme vibration of the entire machine, excessive noise generation, and instability of the servo system.

As a ball screw is supported at both ends with a moving ball nut in the middle, there are different beams with different natural frequencies on either side of the ball nut. These natural frequencies vary as the nut moves along the shaft. Fig. 5 is a graph showing the relationship between natural frequency, the critical speed of a screw shaft and rotational speed.

The operation of a ball screw with a long stroke at high rotational speed has been considered difficult. The wide-ranging natural frequency of screw shafts is one of the reasons. The countermeasure for this, which is to provide the shaft with intermediate support and increase its natural frequency, had been known for some time, but was not reported on until Tamaki et al. explained how they achieved a super high feed rate through the use of this method.

Generally, ball screws are operated with screw shaft rotation; although with a long stroke and when driving several tables with one screw shaft, a rotating ball nut offers advantages in terms of load inertia to driving motors and control. However, problems with critical speed are likely to arise in these cases.

NSK’s nut-rotating type ball screw with built-in vibration damper (patent pending) achieved higher speed through the use of a vibration damper as a countermeasure against the critical speed of the shaft. A peculiarity of ball screws, as mentioned above, is that, since the critical speed of the shaft varies as the nut is moved and the shaft frequency changes, the resonance point is reached only momentarily. For this reason, a simple solution - incorporating a vibration damper in the
hollow screw shaft - achieves outstanding results with only a moderate cost increase and no increase in the ball screw outer dimensions.

Fig. 6 compares the vibration of two screw shafts, one with and one without the vibration damper, at 3 000 rpm. The screw shaft diameter was 20 mm, the lead 40 mm, and the length 2 000 mm. The results clearly demonstrate the efficiency of the vibration damper.

Fig. 7 shows the results of an experiment done on a screw shaft with a diameter of 40 mm and an overall length of 4 100 mm. The nut was moved and a vibration test was done at each point. The results are arranged based on the natural frequency of each nut position and compliance. Due to the vibration damper, great improvement of dynamic rigidity over a wide frequency range was observed.

Photo 2 is a visual comparison of two ball screws, one with and one without the damper, after high-speed endurance tests during which the critical speed was reached. Flaking of the nut groove was observed on the one without the damper after 2 000 km of operation. However, even after 10 000 km, the ball screw with the damper showed nearly no deterioration.

The efficiency of NSK's ball screw with vibration motion & control no. 4 — 1998

Fig. 7 Natural frequency and compliance

Ball screw
Shaft diameter: 20 mm
Lead: 40 mm
Overall length: 2000 mm
Nut rotational speed: 3000 rpm

Fig. 6 Effect of damper on screw shaft vibration

Photo 2 Effect of damper on ball nut groove endurance

(Extent of deterioration of ball nut groove after 5 000 km running)
Fig. 8 Noise level data

Fig. 9 Noise level and lead

Fig. 10 Effect of product improvement on noise level
damper, as illustrated in photo 2, serves to refute previously held notions that high-speed operation of a ball screw with a long stroke was impossible.

### 2.2.3 Increase in vibration and noise

The balls in a ball screw, since they are constantly being re-circulated by the return tube, generate noise and vibration similar to flaw noise of rolling bearings. After determining that ball diameter, \( D_0 \) (which reflects mass) and \( d_{\text{w}}N \) were the dominant factors, we have come up with an equation for the noise generated by a ball screw through the analysis of 4,362 units of measurement data obtained in diverse experiments involving precision ball screws (please see Fig. 8). Using the equation, a noise scale was obtained which can predict the influence of high speed on noise, as well as the effects of quality improvement or new design ideas on noise reduction.

Fig. 9 compares noise generated by ball screws with differing leads at the same feed rate. It shows that making lead longer to reduce rotational speed \( N \) is also one way to reduce noise.

In addition, the quality of the rolling surfaces affects the generation of ball screw noise and vibration. Essentially, higher quality means less noise and vibration. Therefore, methods to improve surface accuracy, such as superfinishing of the screw grooves, have been developed and advanced technology has been applied to the design and manufacturing of ball screw rolling surfaces. In Fig. 10, the noise generated by a single axis table with a ball screw incorporating the above improvements is compared with that of a single axis table with a standard ball screw. As is apparent, significant noise reduction has been achieved.

### 2.2.4 Increase in temperature and thermal deformation

As ball screw speed increases, so too do temperature and thermal deformation. Fundamentally, the ball screw is a feeding screw which uses rolling contact, in place of sliding contact, to reduce friction. For this reason, even though a certain degree of preload is applied to insure high precision, heat generation due to friction is not so high. Nonetheless, heat generation has become an important problem for ball screws for the following reasons:

1. Ball screws directly affect machine positioning accuracy and are required to be highly precise in the longitudinal direction over their entire length.
2. Although the ball screw is an integral part of a machine, most of its surface is exposed to the air making heat transfer with other parts limited.

For this reason, we believe it is important to discuss thermal problems separately from others.

Fig. 11 shows how various factors affect and relate to thermal problems and various countermeasures. Next, these factors and countermeasures will be discussed.

The heat generated by a ball screw is the product of frictional torque and speed:

\[
Q = 0.12\pi NT
\]

Where, \( Q \): heating quantity per unit of time (kJ/hr)
\( N \): rotational speed (rpm)
\( T \): frictional torque (N·m)

The temperature rise is determined by the difference between the heating quantity and the heat transfer value, including forced cooling:

\[
\theta = (Q/\beta) [1 - \exp\{-\beta/CM\cdot t\}]
\]

Where, \( \theta \): temperature rise (K)
\( \beta \): heat transfer value per unit of time, unit temperature difference (kJ/hr/K)
\( CM \): heat capacity (kJ/K)
\( t \): time (hr)

The right part of the equation in brackets, [ ], represents secular change and reflects that the amount of time until temperature stabilization occurs is related inversely to the heat transfer value.
Thermal deformation is determined by the temperature rise, a thermal expansion coefficient and the overall rigidity of the ball screw's surrounding structure, including support bearings, housing, connecting parts, etc. The extent to which machine accuracy is affected by thermal deformation is decided by how well it is compensated for through closed loop control.

Methods for reducing heat generation in ball screws include limiting screw rotational speed by increasing lead length and reducing frictional torque by applying appropriate preloads. Recent efforts on this problem at NSK have produced a ball screw with adjustable preload for which a patent is pending.

A very efficient method for increasing heat transfer in ball screws is forced cooling. NSK’s hollow shaft ball screw series, which features holes in the shaft to allow for efficient coolant flow, uses this method and is becoming increasingly popular in the market. Fig. 12 shows how various cooling methods affect the temperature rise and saturation point of a hollow shaft ball screw. As can be seen, temperature rise and the amount of time until temperature saturation occurs have both been reduced. Among coolants, water is ten times more effective than oil and several thousand times more effective than air because of its lower viscosity and higher thermal conductivity, specific heat and density.

Additionally, many methods focusing on controlling and compensating for thermal deformation, rather than reducing it through cooling, have been developed, including special arrangements of ball screw shaft support and digital compensation via numerical controllers.

2.2.5 Increase in load caused by higher speed and higher acceleration/deceleration

To realize true high speed, it is imperative to increase not only maximum speed, but acceleration/deceleration as well. Especially when driving a heavy mass at high speed and high acceleration/deceleration, such as in a machining center, ball screw load and momentum per unit time increase, necessitating higher load capacity and rigidity.

In response to this challenge, NSK developed its HMC Series ball screws for high-speed machine tools (Photo 3), which incorporate numerous high-speed countermeasures and achieve higher load capacity and rigidity. The HMC Series has the following features:

(1) Its maximum feed rate of 72 m/min was achieved by lengthening the lead, not increasing rotational speed. (lead/screw shaft diameter = 1/2)
(2) Its high-speed endurance limit was increased through improvements in the design of the ball re-circulating mechanism and ball screw grooves.
(3) As a countermeasure to temperature rise and thermal expansion, its hollow shaft enables high accuracy.
(4) While load capacity and rigidity are normally adversely...
3. Responses to Diverse Needs

3.1 High-load drive applications

High-load drive applications utilizing the force-boosting function of the ball screw are increasing. As electrically-powered numerical control replaces hydraulic cylinders in injection molding machines, presses and other machines, the use of ball screws is growing. There are cases in which ball screws are used in injection molding machines to control forces exceeding 50 tons. The requirements for such applications include super-high load capacity and durability, along with a short stroke. To fulfill such requirements, it is necessary to develop ball screws with load capacities higher than ever before, and also to establish technology for selecting the correct ball screw for a given application.

"HTF Series" ball screws (Photo 5) are NSK’s response to market demand for ball screws capable of driving heavy loads. Their super-high load capacity was realized through the following specifications which were made possible by the application of new production and machining techniques:

- Specially-designed groove profile, ideal groove dimensions and optimum ball diameter.
- The return tubes, rather than side by side, are on opposite sides of the nut making the load balanced in the circumferential direction.

Table 4 compares the load capacity of HTF Series ball screws with previous high-load ball screws. Table 5 and Photo 6 compare the results of severe endurance tests done on the HTF Series and previous high-load ball screws. The test results confirm that the durability of the HTF Series ball screws is superior to that of previous models.

Table 2 compares major specifications of the HMC Series with ordinary series.

Photo 4 shows a high-speed and high-acceleration/deceleration work table with a feeding system constructed using an HMC Series ball screw and a new LA Series linear guide for machine tools. (Please see “LA Series Linear Guides” in the New Products section of this journal.) We are presently conducting an endurance test of this work table under very high acceleration/deceleration, repeating high-frequency short-stroke operation. The conditions of this test are outlined in Table 3. Encouraged by the progress shown by the HMC Series in endurance and functional characteristics tests, we are continuing development with our sights set on the next target: achieving a feed rate of 100 m/min.

Table 4. Comparison of HTF Series with conventional products

<table>
<thead>
<tr>
<th>Nut model</th>
<th>Screw shaft diameter (mm)</th>
<th>Permissible dynamic load (N) (target)</th>
<th>Basic static load rating C_{0u} (N)</th>
<th>Basic dynamic load rating C_{a} (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTF Series</td>
<td>80</td>
<td>230 400</td>
<td>1690 000</td>
<td>511 000</td>
</tr>
<tr>
<td>Conventional products</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Std. spec. SFT8020-7.5</td>
<td>80</td>
<td>110 000</td>
<td>874 000</td>
</tr>
<tr>
<td></td>
<td>Special spec. 8020-7.5</td>
<td>80</td>
<td>173 600</td>
<td>1440 000</td>
</tr>
<tr>
<td></td>
<td>Special spec. 10020-7.5</td>
<td>100</td>
<td>225 500</td>
<td>1820 000</td>
</tr>
</tbody>
</table>

---

Table 3. Test conditions of high-speed and high-acceleration/deceleration work table

<table>
<thead>
<tr>
<th>Ball screw</th>
<th>HMC Series (HDF5030-5, shaft diameter: 50, lead: 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear guide</td>
<td>LA Series (LA45)</td>
</tr>
<tr>
<td>Weight to be loaded</td>
<td>19.6 kN (2000 kgf)</td>
</tr>
<tr>
<td>Acceleration/deceleration</td>
<td>1.3 G</td>
</tr>
<tr>
<td>Maximum speed</td>
<td>60 m/min (2000 rpm)</td>
</tr>
<tr>
<td>Running pattern</td>
<td>Step feeding, 100 mm/step</td>
</tr>
<tr>
<td>Stroke</td>
<td>600 mm</td>
</tr>
</tbody>
</table>

* Rigidity value when the preload is 5% of the dynamic load rating.
HTF Series is 2 to 3 times higher than previous high-load ball screws which were specially designed for their particular applications. While developing the HTF Series, we conducted durability tests on a ball screw suitable for high-load/short-stroke applications. During these tests, load and stroke were varied. Using the results, we have come up with a life-estimating equation based on the general rating fatigue life equation, but modified with surface pressure and stroke coefficients:

\[ L = \left( \frac{C_a}{F_a \cdot f_a \cdot f_c \cdot f_L} \right)^3 \times 10^6 \]

Where, \( L \): Rating fatigue life (rev.),
\( C_a \): Basic dynamic load rating (N),
\( F_a \): Axial load (N),
\( f_a \): Load factor,
\( f_c \): Surface pressure coefficient \( f_c = (\frac{P_{max}}{1961})^3 \) provided that when \( P_{max} \leq 1961, f_c = 1 \),
\( P_{max} \): Maximum contact surface pressure (MPa),
\( f_L \): Stroke coefficient \( f_L = 2/S^{1/2} \) provided that when \( S \geq 4, f_L = 1 \),
\( S \): Stroke (rev.).

Especially under such severe conditions, the selection of a suitable lubricant is very important for high durability. NSK provides assistance in selecting suitable greases for high-load ball screws.

### 3.2 Maintenance-free

In an effort to greatly increase maintenance intervals, NSK has developed Molded Oil and used it to create its “NSK K1 Seal”, compact lubricant-supplying units for ball screws and linear guides. As a detailed account of the development and testing of Molded Oil and the K1 Seal has already been given in “Motion and Control” No. 2 (“Development of Molded Oil and Its Application to NSK Linear Guides”), in this article we focus specifically on K1 Seal ball screw applications. Fig. 13 shows the structure of a ball screw with a K1 Seal. Fig. 14 compares test results on the durability of a ball screw for light load transporting with a K1 Seal and one without any lubrication. The test results confirm the high lubricating effectiveness of the K1 Seal. Additionally, durability tests on high-load ball screws for machine tools with grease and K1 Seal lubrication were performed. (The test rig is shown in Photo 7.)

The test conditions were as follows:
- Shaft diameter: 40 mm
- Lead: 20 mm
- No. of effective turns: 2.5 \times 1
- Axial load: 4 700 N
  (Upper limit for this application)
- Stroke: 450 mm
- Speed: 2 000 rpm (40 m/min)
- Lubrication: AV2 grease and K1 Seal
  (Initially packed AV2 grease was not replenished)

After 5 600 km of operation (exceeding the target of 5 000 km), the results were as follows:

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Conventional product</th>
<th>HTF Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Screw shaft diameter: 80 mm, lead: 20 mm, 2.5 turns, 3 circuits</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Maximum axial load: 283 kN</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Maximum contact surface pressure: 2 300 MPa</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Stroke: 100 mm</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Lubrication: Conventional grease</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Total no. of shots: 2.0 \times 10^6</td>
<td></td>
</tr>
</tbody>
</table>

Photo 6  Screw shaft appearance after severe endurance test

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Conventional products</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maximum contact surface pressure: 283 kN</td>
</tr>
<tr>
<td>2</td>
<td>Stroke: 100 mm</td>
</tr>
<tr>
<td>3</td>
<td>Lubrication: Conventional grease</td>
</tr>
<tr>
<td>4</td>
<td>Total no. of shots: 2.0 \times 10^6</td>
</tr>
</tbody>
</table>

Table 5  Results of severe endurance test

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Conventional products</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maximum contact surface pressure: 283 kN</td>
</tr>
<tr>
<td>2</td>
<td>Stroke: 100 mm</td>
</tr>
<tr>
<td>3</td>
<td>Lubrication: Conventional grease</td>
</tr>
<tr>
<td>4</td>
<td>Total no. of shots: 2.0 \times 10^6</td>
</tr>
</tbody>
</table>

Conventional product
Flaking occurred after 1.3 \times 10^6 shots
HTF Series
No abnormality after 6.5 \times 10^6 shots

Especially under such severe conditions, the selection of a suitable lubricant is very important for high durability. NSK provides assistance in selecting suitable greases for high-load ball screws.
(1) Upon visual inspection, running traces of the balls were observed in the grooves, but no abnormality was present.

(2) The total wear of the balls and grooves was evaluated by measuring the clearance between the balls and nut before and after the test with the preload released. The variation in clearance between before and after the test was minimal, less than 0.5 μm.

(3) Other analyses conducted on torque and various components of the ball screw revealed nearly no variations.

A similar durability test under high-load conditions like those of a machine tool with only a K1 Seal for lubrication was conducted in order to assess and improve the maintenance-free attribute of the K1 Seal. After 3 500 km of operation (exceeding the target of 3 000 km), results like those explained above were obtained.

Through the outstanding results of these and other tests, we have confirmed the high efficiency of the K1 Seal in lubricating ball screws, particularly those operating in the high-load conditions of machine tools. In our further efforts, we will focus on accumulating research data to assist in the improvement of the maintenance-free attribute of the K1 Seal.

### 3.3 Clean environments

Semiconductor and LCD production must be carried out in an extremely clean environment. Therefore, the minuscule particles generated by the lubricant when the ball screw rotates must be minimized.

Generally, the amount of particles generated increases...
tenfold when ball screw speed doubles, though this varies greatly depending on the type of grease. Fluorine-based grease, while usually used for vacuum environments, is used under normal atmospheric pressure conditions when high cleanliness is required due to its low particle generation. However, it presents the following problems:

(1) As speed increases, the frictional torque caused by lubrication resistance increases markedly causing heat generation and motor overload.
(2) Compared to ordinary grease, fluorine-based grease is inferior in terms of wear resistance, durability and anti-corrosive properties.

Table 6  Comparison of grease characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>LG2</th>
<th>Grease A</th>
<th>Grease B</th>
<th>Grease C</th>
<th>Grease D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickener</td>
<td>Lithium soap</td>
<td>Lithium soap</td>
<td>Fluorine compound</td>
<td>Lithium soap</td>
<td>Fluorine compound</td>
</tr>
<tr>
<td>Consistency (60 W)</td>
<td>207</td>
<td>273</td>
<td>265</td>
<td>270</td>
<td>250</td>
</tr>
<tr>
<td>Type of base oil</td>
<td>Mineral oil and synthetic hydrocarbon</td>
<td>Mineral oil</td>
<td>Fluorine oil</td>
<td>Ester oil and mineral oil</td>
<td>Fluorine oil</td>
</tr>
<tr>
<td>Kinematic viscosity of base oil (mm²/s, 40°C)</td>
<td>30</td>
<td>130</td>
<td>240</td>
<td>15</td>
<td>350</td>
</tr>
</tbody>
</table>

Fig. 15  Particle generation by grease

Fig. 16  Dynamic torque by grease type

Fig. 17  Effect on wear by grease type
To overcome these problems, NSK developed LG2 clean grease, a low particle-generating grease which retains the positive characteristics of ordinary grease. Table 6 compares basic characteristics of LG2 with four other greases. Test results on particle generation are shown in Fig. 15. They show that different greases generate varying amounts of particles just after being packed. And, more importantly, the test results demonstrate that, after running-in, LG2 is very stable and generates the fewest particles. Additionally, comparative tests were done on LG2 grease and a fluorine-based grease for vacuum environments. Fig. 16 shows test results on dynamic torque and Fig. 17 shows test results on wear resistance. The anti-corrosive properties of LG2 and two other greases are compared visually in Photo 8. All of the test results indicate, LG2 is clearly superior to competing products. Presently, NSK is working on the development of a clean grease with better overall characteristics for high-temperature and vacuum environments.

4. Conclusion

As mentioned in the beginning of this article, with the range of applications for ball screws widening, demand for higher-performance ball screws is diversifying and increasing. In this article, we have presented just a part of the technologies and products NSK has developed in response to the requirements of today’s market.

Other recently developed products include:
1. a series of ball screws with low-inertia rotatable nuts (with reduced outer dimensions of the nut housing and ball bearings installed on the ball nut)
2. “Robotte”*: a series of products combining ball screws and splines (utilizing the same ball nut construction of the low-inertia rotatable nut series)
3. low-priced VFA Series precision ball screws for factory automation

4. RMA and RMS Series miniature rolled ball screws.

Goals for future technology development include:
1. a solid lubricant for outer space and vacuum applications
2. countermeasures for special environments, such as in aircraft and nuclear reactors
3. highly effective sealing technology for preventing dust penetration
4. surface treatment technology for rust prevention and chemical resistance
5. improved stainless steel and nonmagnetic material technology
6. optimum lubrication technology for every specific application.

We will report on the above products and technologies in more detail at another time.

References:

*Photo 8 Anti-corrosive properties of grease

Mizuho Ninomiya

Kazuo Miyaguchi