RECENT TRENDS OF TRIBOTECHNOLOGY IN JAPAN

Yoshitsugu KIMURA
Institute of Industrial Science, University of Tokyo, Japan

INTRODUCTION

Recognition of the importance of saving energy and resources compelled us to develop technology for higher efficiency and longer serviceable life. Tribotechnology in recent years evidently reflects this demand. An updated version of a review is made of selected topics of tribotechnology in Japan, which includes high-speed bearings, bearings for office and home appliances, tribology for magnetic recording devices, tribology in architecture and tribology for automobile.

HIGH-SPEED BEARINGS

A transition from industry for the 'heavy, thick, long and big' to that for the 'light, thin, short and small' has been spoken among journalism after the twofold energy crises. However, the demand for higher efficiency has resulted in developing higher-speed larger-capacity bearings.

Electric power plants of greater capacity have been necessitated by increasing energy consumption. Huge steam turbine generators of 1000 MW in thermal plants and 1180 MW in nuclear plants are in operation. Journal bearings in these machines are characterized by their high speeds. Seemingly, however, the maximum peripheral speed of the shafts in them has been leveled off in the last decade at around 150-200 m/s. Friction loss in a bearing amounts to 500 kW, which necessitates designing bearings based on thermohydrodynamic theories.

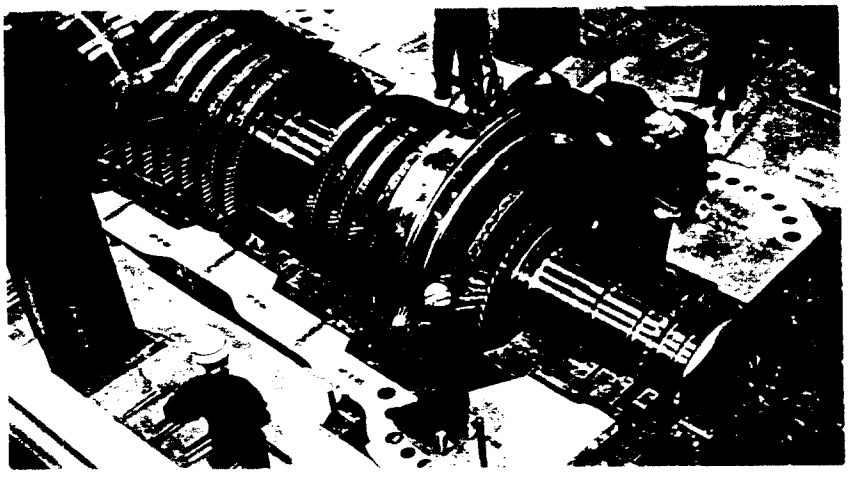

Fig. 1 Part of a 1100 MW steam turbine generator

On the other hand, hydroelectric plants of larger capacity are being constructed. Typically, capacity of pumped-storage hydrogenerators has increased from 100 to 400 MVA, and large-capacity thrust bearings have been required. In these large bearings, control of thermal distortion is essential for ensuring optimal hydrodynamic conditions under a load as high as 50 MN. For this purpose, direct water-cooled tilting pads are employed, which have piping to circulate cooling water just beneath the backing metal. This reduces the maximum oil-film temperature by 40-45° C.

Typical examples of high-speed rolling contact bearings can be found in main bearings in jet engines. Although jet engines are developed based on US and European technology, their ball and roller bearings are being manufactured also in Japan. The dn value, the product of inner diameter in mm and rotational frequency in rpm, of these bearings exceeds 2 millions, which needs special materials for higher operating temperatures, special design for efficient cooling and special lubricants as well.

Use of engineering ceramics for rolling contact bearings captured attention of tribologists and bearing engineers. First, it was tried to develop 'all ceramic bearings' aiming at operation at elevated temperatures without lubricating oil. However, their immense cost has prevented their success in the market. Another trial then followed to use ceramic material, typically silicon nitride, for rolling elements, while races were made from conventional bearing steel. Although lubrication is necessary and operating temperature is limited, low density of silicon nitride has contributed to reducing centrifugal load at high-speed operations, which found a market in machine tools.

BEARINGS FOR OFFICE AND HOME APPLIANCES

The development of mechatronics has produced various novel office and home appliances having small-size bearings. As a result of introduction of these appliances, we live today surrounded by a tremendous number of bearings. Such a situation has required bearings of quiet operation and maintenance-free long lives, as well as compactness and moderate prices, in addition to low friction and low wear rates.

An example is provided by the ball bearings for rotary-drum heads for videotape decks being exported worldwide. They are often made so that their balls rotate in a groove directly formed around the shaft. Their radial run-out is about 0.15 μm; their noise level when running at 1800 rpm detected at a distance of 10 cm is about 40 dB, which means normal ears hardly catch the noise at a distance of 1 m. This has been realized by fabricating their balls at a maximum out-of-sphericity of 0.05 μm.

Rolling bearings have favorable features to the use for home and office appliances, i.e. high running accuracy, low running as well as starting torque with easy lubrication. They are in wide use, of course, but are being partially replaced in some uses by air-, oil- or grease-lubricated hydrodynamic bearings having helical grooves for quieter operation, and by porous hydrostatic air bearings for still higher accuracy.

Positioned in between them, a hybrid bearing has been developed for these uses. An integrated PEEK inner-race/retainer houses steel needle rollers in

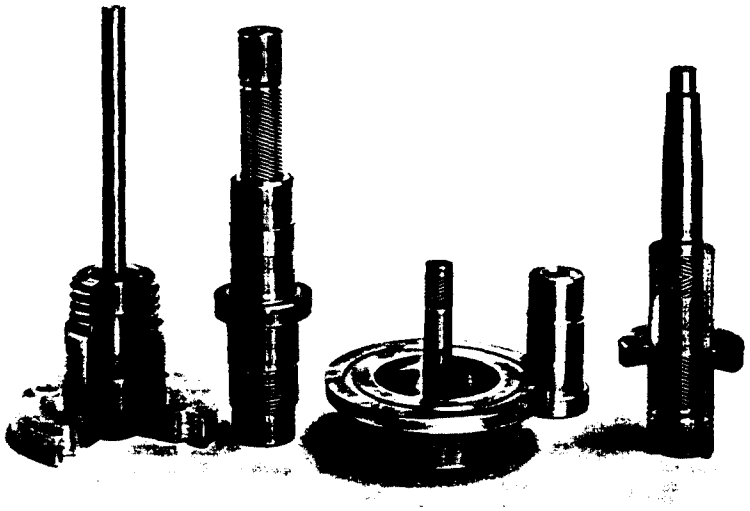

Fig. 2 Helical groove bearings

the slots on its periphery. The rollers make sliding contact with PEEK, while making rolling contact against a pressed stainless-steel outer race, lubricated with sealed plastic grease. This bearing is characterized by reasonably low friction and a long life as well as quite easy installation in thin cylindrical spaces.

Ferrofluids are being tried for the use as lubricant as well as for sealant. In a polygon mirror drive unit, its spindle is supported by a pair of plain bearings lubricated with a ferrofluid which is suspension of ferromagnetic powder of about 0.01 μm average diameter in oil. When compared with gas bearings which have been replaced, the ferrofluid bearings show higher stiffness and longer life, and combination with a ferrofludic seal makes the unit compact.

TRIBOLOGY IN MAGNETIC RECORDING DEVICES

The development of information-related machinery in recent years has brought about a number of new tribological problems. It is most marked with magnetic storage systems for high-speed computers, with which a spectacular progress has taken place to increase the recording density. The systems having area recording density as high as 150 kbit/mm^2 are in the market. These have been achieved by employing magnetoresistive heads, thin-film recording media and perpendicular recording, and by reducing the minimum head-to-disk spacing, all of which are characterized by a decrease in dimensions.

Although the heads are 'flying' in normal operation, it is required 'to take off' at the starts and 'to land' at the stops of the devices. In order to protect the records against possible damage, the disk surface tolerates wear

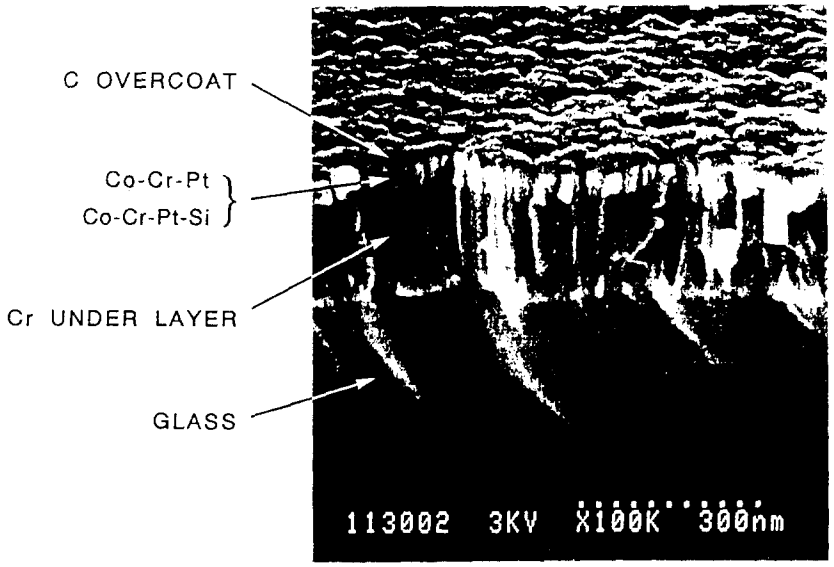

Fig. 3 Cross section of a recording disk

within the order of an atomic layer during several hundred thousand starts and stops. This poses a quite tough tribological problem. Together with employing an effective overcoat layer, a lubricant film of perfluoropolyether derivatives of a few nanometer thickness is usually applied onto the surfaces. A series of STM observations have revealed the behavior of a lubricant molecule anchored on a graphite surface at its benzene ring parallel to the surface without shifting in three subsequent scannings. This and similar nano-scale observations seem to bring novel information about the mechanisms of boundary lubrication.

Design of floating heads also captures attention. If only steady, unidirectional 'flying' is required, simple design like a sleigh must have been sufficient. In practice, however, a head has to trace tracks at different radii on a disk, and to transfer from a track to another in seeking operations, while keeping a substantially constant flying height. This necessitates sophisticated design of their bearing surface.

TRIBOLOGY IN ARCHITECTURE

Buildings and structures which are apparently at rest also need tribotechnology. Although heavy loads are common, high-speed motion seldom occur; this feature results in exclusive use of solid lubricants.

Examples are found in monster bridges. Developing construction technology enabled to tie the four major islands of Japan with tunnels or bridges. A chain of bridges were built across the Seto inland sea to connect Honshu main island and Shikoku. The Shimotsui-Seto bridge, the northernmost one, is a suspension bridge. Its double-deck girder of 1416 m in length carrying a highway and a double-track railway is suspended by two pairs of pendulum links from the towers to allow oscillation of nearly 1 m in the peak-to-peak ampli-

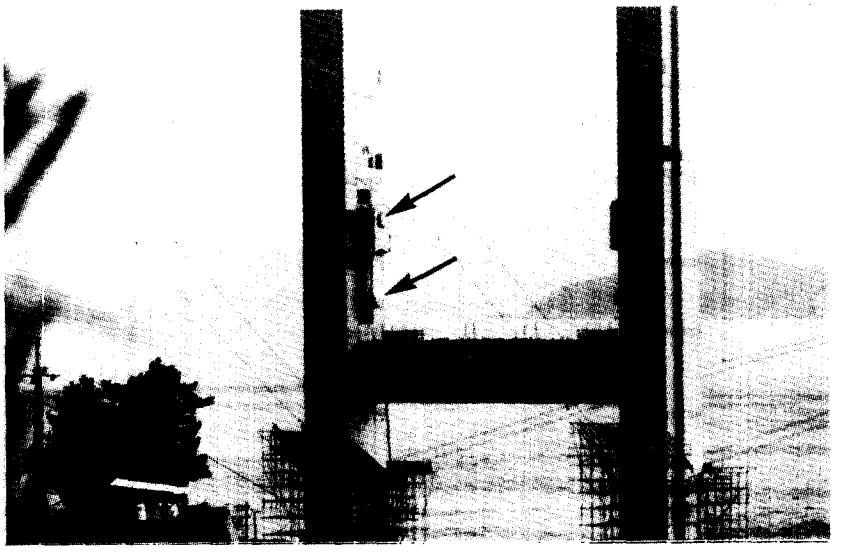

Fig. 4 Tower of a huge suspension bridge being built

tude caused by dynamic loads. The links have bearings at both ends, each of which carries a load of 50 MN and is required to last for 100 years. The bearings are brass bushes, each weighing 2.7 t with embedded PTFE-based solid lubricant.

Seismic isolation systems for buildings are being developed which employs an actively controlled friction damper. In normal base-isolated buildings using passive isolation devices, it is impossible to satisfactorily reduce both the horizontal displacements between the ground and the superstructures and their response accelerations simultaneously. A seismic isolation system using a controllable friction damper has been developed, in which a copper-based sintered pad is pressed against a steel surface by oil-hydraulic pressure. The system senses the relative displacement and the actual pressure, which are fed back to regulate the pressure. A series of model experiments have revealed that the displacements are halved with similar acceleration levels when compared with a passive system.

TRIBOLOGY FOR AUTOMOBILE

Recognition of finite energy resources enhanced the research on tribology for energy saving after the energy crises. The motivation has been further strengthened by warnings on the green-house effect and strict regulation of the corporate average fuel economy of automobiles. In Japan, automobiles have been one of the most important products for export and their high fuel economy has sold them as well as their high reliability.

In piston-cylinder systems, which are the most important parts causing friction losses in automobile, a number of new technologies have been developed. First, various surface modifications are employed for piston rings, which have contributed to reducing coefficient of friction while keeping efficient seal-

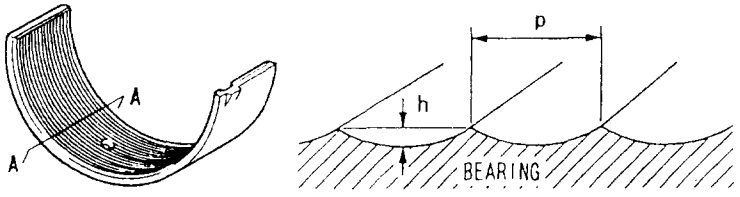

Fig. 6 Microgrooved bearing

ing of gases as well as lubricant. Secondly, in order to maintain good lubrication in both hydrodynamic and boundary regimes, piston skirts are formed into a slight barrel shape and solid-lubricant coating is applied on them.

The use of light metals, typically aluminum alloys, contributes to reducing vehicle weight. An example is found in a newly developed aluminum engine block without cylinder liners of cast iron. The engine block was made of 10 % Si aluminum alloy, and its cylinder bores were 'compositized' to improve seizure and wear resistance. That is, thin cylindrical fiber preforms were made of a mixture of short alumina and carbon fibers; they were placed around the bores, and the aluminum alloy was cast at a medium pressure. This engine has shown comparable anti-wear property at the bores as well as the total friction loss to those of cast iron, while achieving 50 % weight reduction for the same power output.

Crank-shaft bearings must be one of the most thoroughly studied tribological components in automobile. They are typical high-load bearings which are required to operate under a unit load as high as 50 MPa at several thousand revolutions per minute. Further, lubricant temperature has been increasing since exhaust gas recirculating systems were employed. These require the bearings to have high scuffing resistance. A novel design of microgrooved bearings is developed in which the surface is provided with fine shallow circumferential grooves. The grooves increase lubricant flow while establishing sufficient hydrodynamic pressure.

Many tribological failures have been experienced in the cam-follower system in valve trains, which has to make rolling-sliding contact under high pressures up to 3 GPa. Systematic selection of adequate materials as well as use of ceramic tips greatly reduced the danger of excessive wear, scuffing and pitting. Further, employing a 'roller rocker' has contributed to decreasing friction loss at lower operating speeds.

Low-viscosity engine oils having high viscosity index have been developed to reduce viscous losses of the components operating under the hydrodynamic lubrication regime over a wide range of operation temperature. However, this increased the part played by the boundary lubrication, and effective friction modifiers have then been introduced to result in a reduction of as high as 10

% of fuel economy.

About 75% of passenger cars in Japan are equipped with an automatic transmission, and smooth engagement of oil-immersed clutches is crucial for driving amenity. Desirable characteristics are that the coefficient of friction is constant or slightly increases with increasing speed, causing apparent contradiction to common Stribeck curves. This problem has been solved by combination of sophisticated formulation of automatic transmission fluids and skillful design of paper-base friction facings.