Technical Trends of Bearings for Steelmaking Equipment

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Steelmaking equipment operates under severe conditions. Likewise, the bearings used in this equipment have requirements for longer life and higher added value. This report describes the development efforts regarding bearings for rolling mills (bearings for roll necks and bearings for multi-roll rolling mills) and bearings for continuous casting equipment.

***Key Words**: bearing, rolling mill, continuous casting, long life, maintenance free, technical trend*

1. Introduction

Steel is a very important product that is used in every industry such as automotive, construction equipment and shipbuilding industries. Steel products are produced with various types of steelmaking equipment in response to the needs of each specific industry and the required operating conditions of this equipment are typically very severe. Moreover, as recent economic growth has expanded demands for steel products, the efficiency improvements and the stable operation of the steel making equipment have become indispensable.

In these circumstances, the bearings used in steelmaking equipment are required to have longer service life and higher reliability while operating under severe conditions. In response to these needs, JTEKT has developed various bearing products.

2. Operating Environment of Bearings for Steelmaking Equipment

Bearings for steelmaking equipment are often used in very severe conditions. Also bearings in every industry are used under various kinds of severe conditions. For instance, the bearings used in automobiles, railway stocks and aircrafts are required to have ultimate reliability, as due to safety reasons, they are never allowed to fail during operation. While bearings used in machine tool spindles are required to have ultra-high rotational speed performance and high running accuracy. Thus, bearings used in every industry are subject to different kinds of severe operating conditions. Among them, from the standpoint of the load on the bearing, the operating environment in steelmaking equipment is extremely severe for bearings.

2. 1 Load and Rotational Speed of Bearings

Figure 1 shows the relation between Dn × N (Dn: bearing bore dia. (mm), N: rotational speed (min^{-1})) and P/C (P: dynamic equivalent load (kN), C: basic dynamic load rating (kN)) in various applications. In this figure, the Dn × N value of the bearings for continuous casting machines is extremely small, that is, around 1 000, while P/C is large, more than 1. This shows that the bearings for continuous casting machine are used at extremely low speeds under very heavy loads. The loading condition is very severe and also, due to slow rotational speeds, the oil film formation in the bearing is extremely difficult.

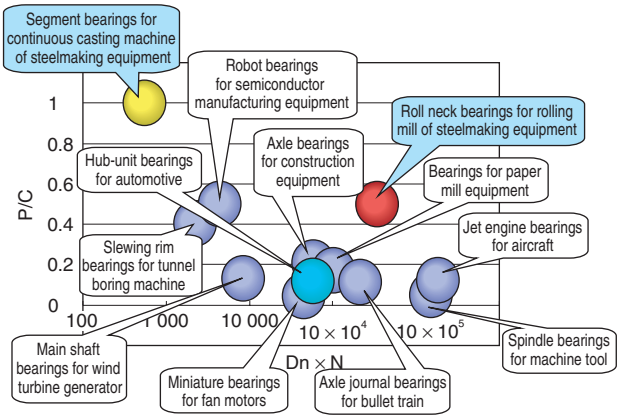

Fig. 1 Bearing load ratings and rotational speeds

On the other hand, concerning bearings for rolling mills, the Dn × N value is 10×10^4 or more and the P/C value is relatively large, around 0.5. The bearings for this application are required to adjust with both heavy load and high rotational speed. In addition, in the rolling mill applications, the bearings are required to endure repeated cycle through rapid acceleration and deceleration from extremely low to high rotational speeds. To satisfy these conditions, cages with sufficient strength and anti-wear raceways need to be implemented.

2. 2 Operating Environment

Figure 2 shows the ambient temperature and the lubrication conditions for bearings in various applications. The lubrication condition is rated taking into account the lubricating system (10 levels), the load and the lubricating condition (12 levels) and the rotational speed (6 levels). **Figure 2** also shows the added values of all these rated levels. In the steelmaking equipment, especially in the processes of continuous casting machines and hot strip mills, bearings are operated at high temperature. To make the matter worse, as the steel products are cooled during the rolling process, rolling mill oil or scale is liable to intrude into the bearing. Consequently, proper oil film formation inside the bearing is often difficult to obtain. There have been various improvements to prevent the intrusion of the rolling mill oil or the scale into the bearing, however, it is still not easy to completely prevent their occurrence due to the extremely severe conditions.

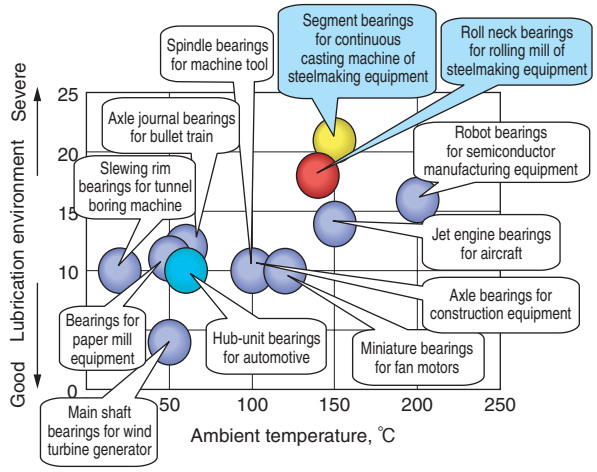

Fig. 2 Bearing ambient temperature and lubrication conditions

In response to such severe operating conditions, JTEKT has developed various bearings satisfying the needs of each steelmaking equipment. Typical examples are introduced as follows.

3. Technical Trends of Bearings for Steelmaking Equipment

3. 1 Roll Neck Bearings for Rolling Mills

The rolling process is an important process that determines the quality of the steel products. Various rolling mills have been developed for each of these rolling processes. **Figure 3** shows the appearance of a typical four-high rolling mill. For the work roll neck, compact type four-row tapered roller bearings with high load carrying capacity are generally applied. For the back-up roll neck, four-row cylindrical roller bearings for radial support and double-row tapered roller bearings for axial support are adopted. The lubrication systems for these bearings have been either grease lubrication, forced oil circulation, oil mist lubrication, or recently, oil/air lubrication.

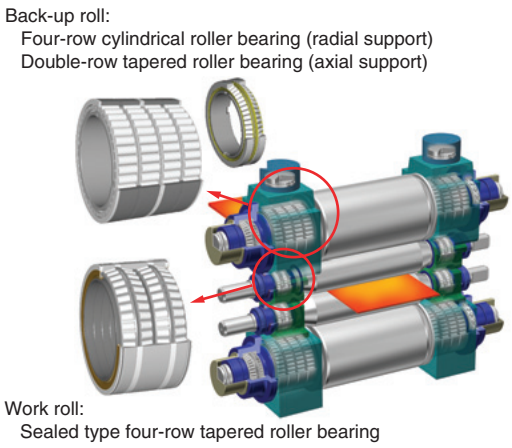

Fig. 3 Rolling mill structure and roll neck bearings (four-high stand)

3. 1. 1 Work Roll Neck Bearing

Four-row tapered roller bearings are used to support the work rolls. As they have traditionally been open type bearings, they have been replenished with large volumes of grease at regular intervals to prevent the bearing from being damaged by the intrusion of rolling mill oil or scale. In order to reduce this grease consumption and prevent their intrusion, JTEKT has developed the sealed type four-row tapered roller bearing with integrated oil seals. This design has contributed to the reduction of pollution of the surrounding environment and the elimination of re-greasing. However, due to the extended overhaul and cleaning intervals, the damage due to their intrusion (wear and/or rust on raceway) has recently occurred again (**Fig. 4**, **Table 1**). Therefore, JTEKT has pushed forward the project to improve the life of the sealed type four-row tapered roller bearings through failure mode analysis as shown in **Fig. 5**.

Fig. 4 Example of work roll neck bearing failure

Table 1 Application history of work roll neck bearing failure

Application	Cold strip mill work roll
Service period	About 6 months
Bearing appearance	Rust and flaking occurred on outer ring raceway

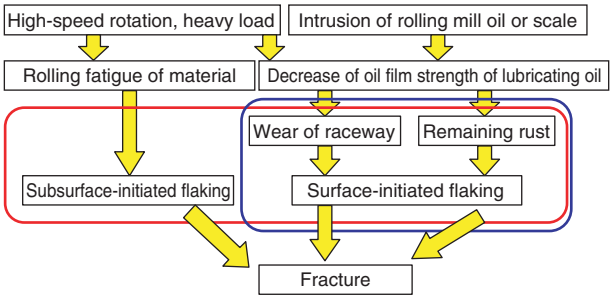

Fig. 5 Failure mode of sealed type four-row tapered roller bearing

(1) Development of Long-Life, High Corrosion-Resistant Steel

When rolling mill oil and scale intrudes into the bearing, they may cause rust between the raceway and the rollers, from which flaking is initiated. Also, the breakage of oil film due to their intrusion may cause wear on the rolling surfaces of raceways and rollers, from which surface-initiated flaking may occur. In order to improve both problems, JTEKT has developed a new long-life, high corrosion-resistant carburizing steel with optimized content of chromium and molybdenum. Additionally, original carbonitriding heat treatment has improved corrosion-resistance and wear-resistance qualities while maintaining the toughness of the steel. Details of the development of this new steel are presented in another paper in this issue entitled "Development of Long Life Case-Hardened Bearing Steel with Rust Resistance." It has been confirmed that the flaking due to rust could be restricted by the use of the newly developed steel and the carbonitriding heat treatment (**Fig. 6**, **Table 2**).

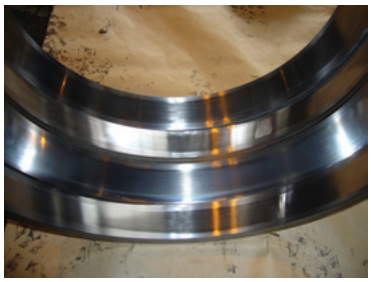

Fig. 6 Post-use appearance of bearing made from developed steel

Table 2 Application history of bearing made from developed steel

Application	Cold strip mill work roll
Service period	About 9 months
Bearing appearance	No rust occurrence on outer ring raceway
Water content in grease	About 5%

(2) Development of High-Sealing Performance Seals

It is presumed that, in addition to extending the bearing life by the development of high corrosion-resistant steel, we can also dramatically extend bearing life by completely preventing the intrusion of rolling mill oil and/or scale into the bearing, which is the major cause of failure through the use of enhanced seals. Moreover, if high sealing performance can be maintained, a longer maintenance interval can be achieved. Based on this concept, JTEKT has developed the high-sealing performance seal in collaboration with Koyo Sealing Techno Co., Ltd. (**Fig. 7**)

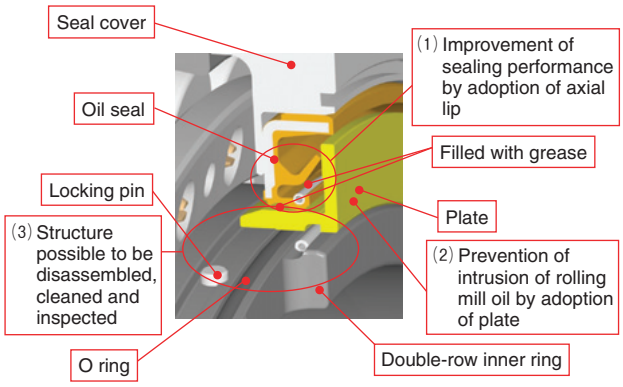

Fig. 7 Structure of high-sealing seal

<Features>

(1) The additional axial lip can significantly prevent the intrusion of rolling mill oil with its fluid-slinging effect.

(2) Adoption of the plate on the end surface of the bearing reduces the amount of rolling mill oil and/or scale exposed to the seal lip.

(3) As the maintenance of the roll neck bearings for the rolling mill is required at regular intervals, a bearing design which facilitates easy assembly and disassembly for inspection has been adopted.

Figure 8 shows the appearance of the high sealing-seal bearing used in an actual hot strip mill. **Table 3** shows the state of the grease in the developed bearing. This bearing has been in use for about a year without any disassembly, cleaning and re-greasing. Low water content in the grease and little to no rust generation is proof of excellent sealing performance.

Fig. 8 Post-use appearances of bearing with high-sealing performance seal

Table 3 Application history of bearing with high-sealing performance seal

Application	Hot strip mill work roll
Service period	1 486 h (Without any maintenance or re-greasing)
Bearing appearance	Good, no flaking and slight wear
Grease penetration	About 280 (New: 300)
Water content in grease	About 1%

3. 1. 2 Back-Up Roll Neck Bearing

Typically in the past, oil film bearings have been used in the back-up roll of rolling mills. Recently however, more and more rolling bearings for especially cold rolling mill are being employed in response to the needs of the improvement of the gauge accuracy. Also, for plate mill and hot rolling mills, the rolling bearings have been increasingly used to improve both the product quality and the yield of production.

By promoting the modification by replacing the oil film bearing with rolling bearing for back-up roll of cold, hot and plate rolling mills, JTEKT has contributed to the improvement of the quality of the rolled steel products (**Fig. 9**)[1), 2)]. Details of these modification projects are presented in another paper in this issue entitled "Modification Method of Back-Up Roll Bearing by Replacing Oil Film Bearing with Rolling Bearing."

3. 2 Back-Up Roll Bearings for Multi-Roll Rolling Mills

The back-up roll bearings in multi-roll rolling mills as shown in **Fig. 10** are characterized by having several bearings installed on a shaft in series. The outer rings of these bearings are in direct contact with the intermediate rolls, and rotate while carrying the rolling force. Additionally, a significant characteristic of lubricant is

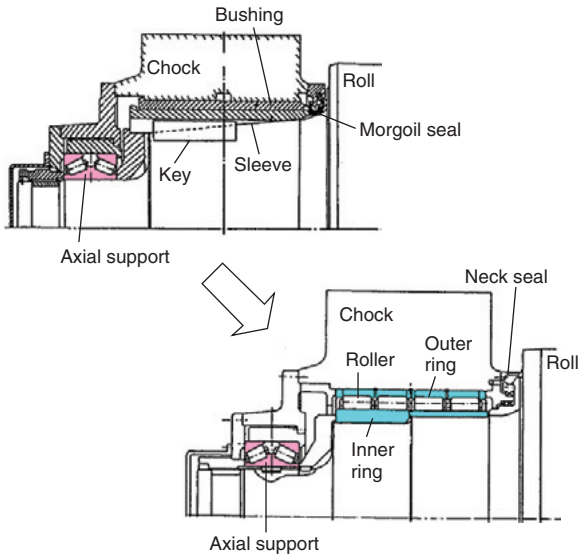

Fig. 9 Replacement of oil film bearing with rolling bearing for back-up roll of rolling mill[1), 2)]

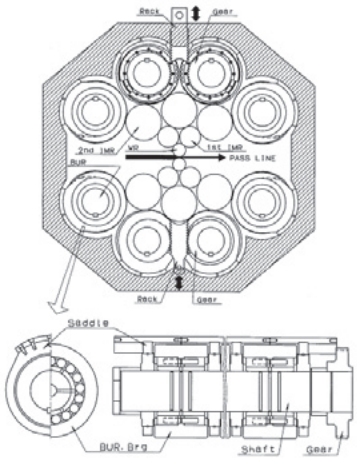

Fig. 10 Structure of back-up roll for multi-roll rolling mill

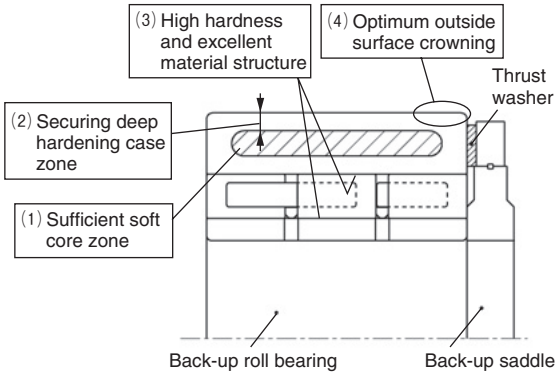

Fig. 11 Required characteristics on back-up bearings for multi-roll rolling mill[1)]

that very low viscosity oil is used. Based on JTEKT long experience in manufacturing and supply of these bearings, various improvements have been implemented to achieve higher reliability and longer life. These improvements are illustrated in **Fig. 11**.

3. 2. 1 Core Hardening and Special Crowning on Outer Ring

For the rotating outer rings, JTEKT has developed the original core hardening method and proceeded to mass production.

<Features of core hardening method>

(1) Impact resistance is ensured by sufficiently thick soft core (**Fig. 12**).

(2) Sufficient case depth can ensure bearing stiffness and provide increased regrinding allowance of outside diameter surface (**Fig. 13**)[1), 3)].

(3) Higher fatigue strength is achieved by excellent material microstructure.

(4) Appropriate crowning is adopted on outside diameter surface to protect intermediate rolls from damage due to load concentration at edge area (**Fig. 14**).

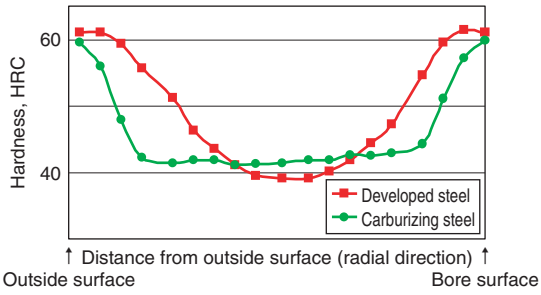

Fig. 12 Hardness distribution of core hardening[1), 3)]

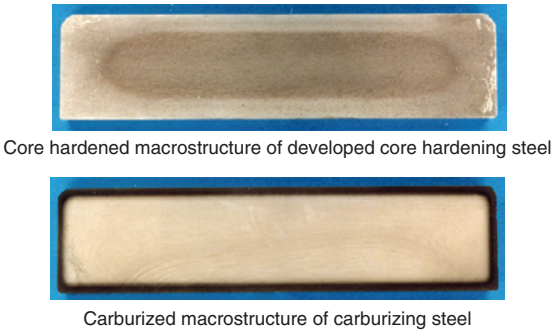

Fig. 13 Macrostructure of developed core hardening steel and carburizing steel[1), 3)]

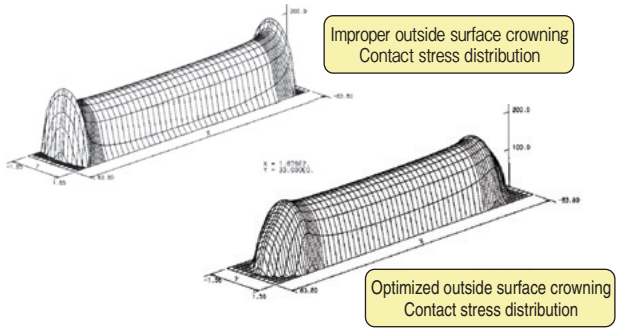

Fig. 14 Comparison of contact pressure of outer ring outside surfaces with/without crowning

3. 2. 2 Grinding Tool for Back-Up Roll Bearings of Multi-Roll Rolling Mills

Since the back-up roll bearings of multi-roll rolling mills are used with their outer ring outside surface in direct contact with the intermediate rolls, the accuracy and the roughness of the outer ring outside surface significantly affect the surface accuracy of the rolled steel product. In order to maintain the bearing accuracy, the outer ring outside surface is reground at regular intervals. To meet this need, JTEKT has developed and commercially supplied various types of grinding tools for improvement of the running accuracy and productivity (**Fig. 15**).

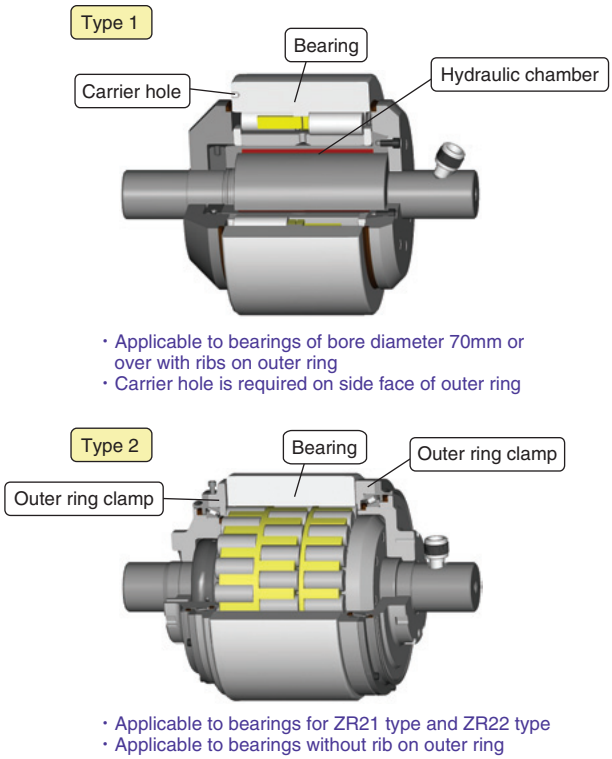

Fig. 15 Grinding tools for back-up bearings of multi-roll rolling mill

3. 3 Bearings for Continuous Casting Machines

As shown in **Figs. 1** and **16**, the bearings utilized in continuous casting machines are characterized by requiring carrying very heavy loads. In extreme case these loads are heavier than the dynamic load ratings of the bearings themselves. In addition to these heavy loads, the bearings are required to operate in extremely low speed less than three revolutions per minute. Furthermore, with high temperature molten steel being solidified, the bearings are exposed to high temperatures and high humidity as well as intrusion of scale. **Figure 17** shows a typical fracture mechanism of a spherical roller bearing for continuous casting machine.

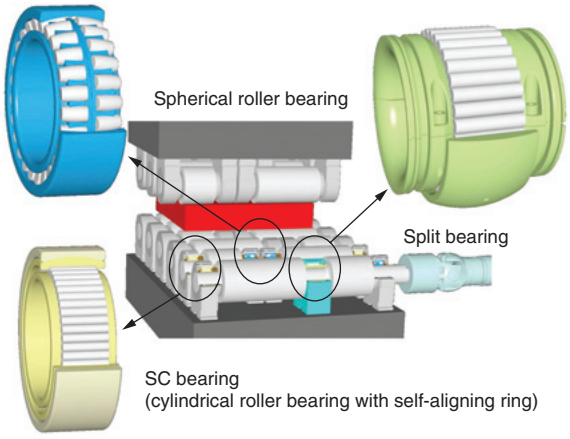

Fig. 16 Continuous casting machine roll structure

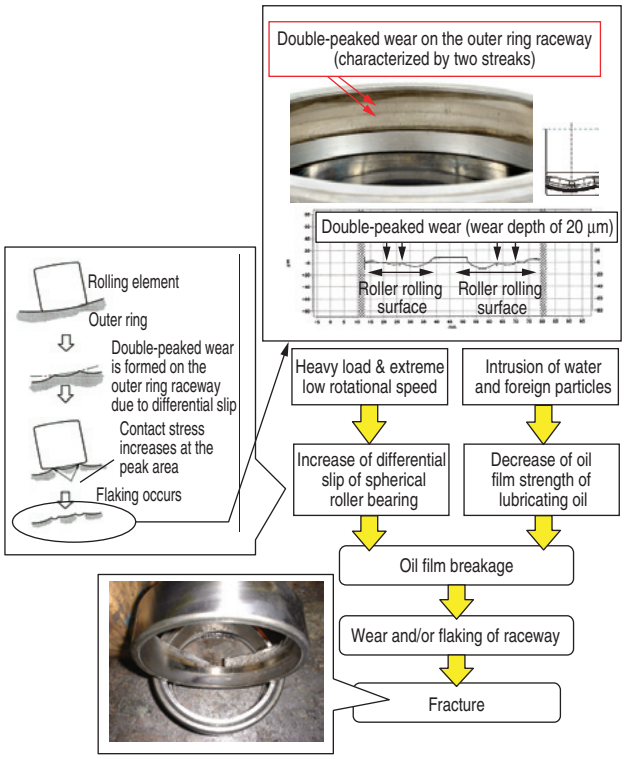

Fig. 17 Fracture mechanism of spherical roller bearing for continuous casting machine

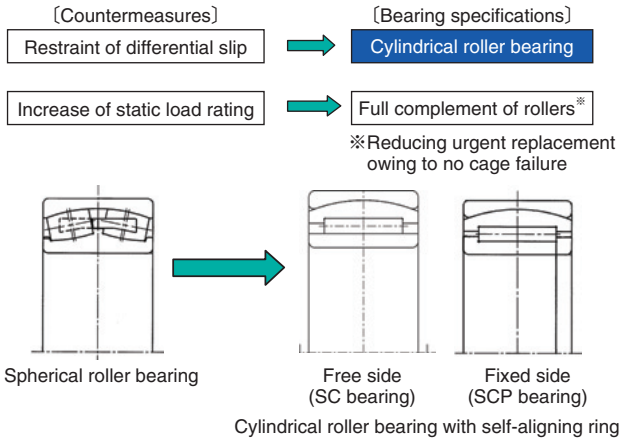

Fig. 18 SC and SCP type cylindrical roller bearings

JTEKT has performed extensive research and evaluation of the loads applied to bearings in steelmaking equipment. Based on the findings, it has been concluded that restraint of differential slip and increase of static load rating of the bearing could achieve longer bearing life. Finally, we have succeeded to develop the SC and SCP type cylindrical roller bearings (**Fig. 18**).

The SC type cylindrical roller bearing is used at the free side and designed to allow the inner ring to move axially so that thermal expansion and contraction of the roll can be accommodated. The SCP type bearing is used at the fixed side and supports the axial load with ribs provided on the inner and outer rings. Both SC and SCP type bearings are designed for high load carrying capacity and optimized static load ratings through the utilization of a full complement cylindrical roller bearing. In addition, they are provided with special crowning on the rollers for heavy loads. **Figure 19** shows a remarkable reduction of replacement ratios in actual machine when changing from spherical roller bearing to the SC type bearings. This replacement reduction is contributed to the improvement of the bearing reliability by the use of SC type bearings.

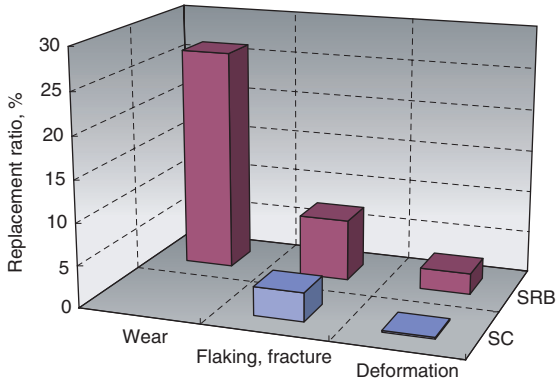

Fig. 19 Failure comparison between spherical roller bearing and SC cylindrical roller bearing after actual use

4. Improvement of Lubrication System (Oil/Air Lubrication System)

With a view to improve lubrication performance of rolling bearings for steelmaking equipment, JTEKT has promoted the development of equipment used to improve the oil film formation in the bearings. **Figure 20** shows the principle of oil/air lubrication systems[4] wherein a relatively small quantity of oil is intermittently supplied into a continuous flow of compressed air. The oil supplied first sticks to the inside wall of the circulation pipe where the oil layer is leveled, and then, carried to the bearing in the form of a continuous oil film by the compressed air.

Table 4 shows the features of oil/air lubrication systems in comparison with the grease lubrication systems. In the case of grease lubrication, the pressure inside the bearing varies to negative pressure depending

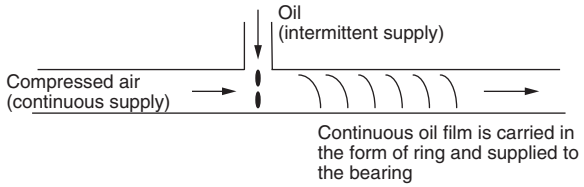

Fig. 20 Principle of oil/air lubrication[4)]

Table 4 Features of oil/air lubrication

	Oil/air lubrication	Grease lubrication
Bearing internal pressure	Positive: 0.01～0.02 MPa ↓ Substantial reduction of intrusion of rolling mill oil	Atmospheric pressure, negative: 0～－0.01 MPa ↓ Negative pressure due to temperature change induces intrusion of rolling mill oil
Running cost	1	2
Maintenance	Cleaning of bearing is not required	Cleaning of bearing is required
Initial cost	High	Low

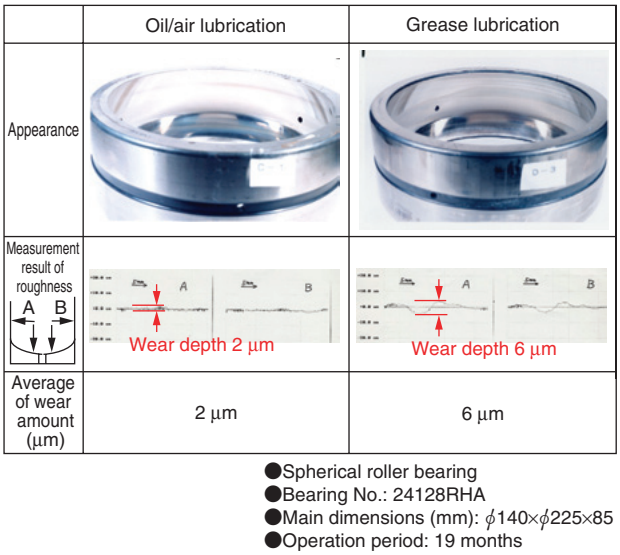

Fig. 21 Bearing appearance for continuous casting machine after use under oil/air lubrication and grease

on the atmospheric pressure or the temperature change. When the pressure inside the bearing becomes negative, rolling mill oil or scale becomes more liable to intrude into the bearing. On the contrary, in the case of oil/air lubrication, the bearing internal pressure is kept positive by the constant supply of the compressed air, and hence, the intrusion of rolling mill oil or scale is prevented. In addition, since a certain amount of oil is constantly supplied to the inside of the bearing, it can extend the bearing maintenance interval which requires disassembly and cleaning compared to that of the grease lubrication.

Figure 21 shows the comparative results of wear of the bearings used in the continuous casting machines, indicating that the wear of the oil/air lubricated bearing was reduced to 1/3 of that of the grease lubricated bearing.

5. Conclusion

As shown in this paper, the bearings in steelmaking equipment are used under very severe conditions. In response to these conditions, JTEKT has proposed various improvements in bearing and surrounding component designs, component materials, lubrication systems, etc, which have contributed to the extension of maintenance intervals, longer bearing life, and a marked improvement in the quality of the steel being produced.

The recent steel mill industry has experienced a remarkable increase in world-wide demand. Furthermore, environmental constraints are becoming more and more demanding. As a result steel mills are being forced to become more efficient and environmentally friendly in their steel production. Therefore, bearings for steelmaking equipment will require having more added values such as maintenance-free, intelligence features and environmental friendliness. JTEKT understands these pressures, and will continue design efforts to develop and deliver new products to meet these market demands.

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