

Modification Method of Back-up Roll Bearing by Replacing Oil Film Bearing with Rolling Bearing

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As back-up roll bearings in rolling mills must support several thousand tons of rolling force, it is known that their running accuracy has significant effect on the gauge accuracy. In cold rolling mills, regarding which the requirement for gauge accuracy is severe, it is particularly critical to keep good running accuracy. Steelmakers have taken various approaches to improving gauge accuracy, one of which is modifying the rolling mills by replacing the oil film bearings with rolling bearings. Since JTEKT in 1984 became the first in Japan to carry out such plate rolling mill modification by the back-up roll bearing replacement, JTEKT has carried out numerous such modifications, including the tandem cold mills. This paper presents JTEKT's method of the rolling mill modification by replacing the oil film bearings with rolling bearings as the back-up roll bearing.

Key Words: four row cylindrical roller bearing, oil film bearing, back-up roll, rolling mill

1. Introduction

In recent years, steel sheets and plates used in various industries, such as shipbuilding and automotive industries, have been required to have high precision as well as high quality. Due to this fact, steel manufacturers have tackled the challenge with various approaches from improving the strength of the rolled material or the gauge accuracy in the rolling, etc. For the improvement in the gauge accuracy, new rolling mills that utilize improved gauge control technology in both longitudinal and lateral directions of the rolling plate have been developed, e.g. 6-high rolling mill or pair-cross rolling mill¹⁾.

In addition to these approaches, there have also been efforts to improve the running accuracy of the back-up rolls of the rolling mills. Since the back-up rolls of the rolling mills have to support several thousand tons of rolling force, their running accuracy has significant effect on the gauge accuracy, and especially on the cold rolling mills (including non-ferrous rolling mills) where the requirement for the gauge accuracy is more severe. In the Japanese market, for the back-up rolls of tandem cold mills installed since the 1980s, the rolling bearings which improve rotational accuracy have been applied as standard instead of the oil film bearings.

Replacement of the oil film bearing with the rolling bearing in the back-up rolls began in 1984 (first case in Japan)²⁾, since then there have been multiple projects to replace the oil film bearings with the rolling bearings on the cold rolling mills.

Here, JTEKT's method of the rolling mill modification

by replacing the oil film bearings with the rolling bearings and its effects are presented.

2. Evolution of Back-up Roll Bearings

The steel rolling process began around the 18th century. Initially, the bearings supporting the rolls were sliding bearings, which had problems in load carrying capacity and high-speed capability. In 1925, the world's first rolling bearing was adopted on a 4-high cold copper rolling mill in U.S.A. This mill was successful to some extent, but it still had a couple of drawbacks such as the decrease of the roll strength due to reduced roll diameter and the reduction of allowable load carrying capacity in high speed rolling. Thereafter, in 1935, the world's first oil film bearing of a sleeve type with a forced oil supply system was adopted on an 80 inch 3-stands tandem cold mill. Since the oil film bearing enabled high-speed rolling under heavy pressure, the oil film bearings were widely adopted as the back-up roll neck bearings on both cold and hot rolling mills³⁾.

Also in Japan, the oil film bearings were used widely on the back-up rolls of cold rolling mills until the 1970s. Around that time, however, customer demands for the improved gauge accuracy of the rolled products made it necessary to use the rolling bearings instead. In a 5-stands tandem cold mill, newly installed in 1972, a JTEKT-made 4-row cylindrical roller bearing ($\phi 900 \times \phi 1230 \times 870$ mm) was adopted on the back-up rolls of each mill stand. Among various types of the rolling bearings, the 4-row cylindrical roller bearings excel in load carrying

capability as well as high-speed operation. High running accuracy of the back-up rolls can be achieved by applying the tight fitting of the inner ring onto the roll journal, and then applying the integral system grinding of the inner ring raceway. Thanks to these advantages, the 4-row cylindrical roller bearings have been applied as the standard bearings for the back-up rolls of the cold rolling mills newly installed in Japan since the 1980s.

Figure 1 shows the 4-high rolling mill and the 4-row cylindrical roller bearing used on its back-up rolls.

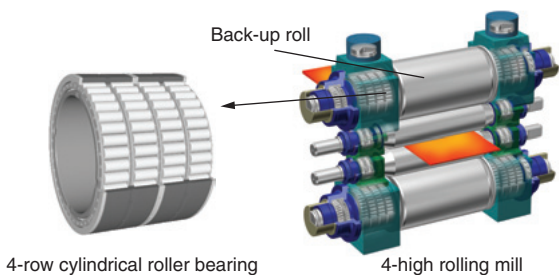


Fig. 1 Four-high rolling mill and 4-row cylindrical roller bearing

In 1985 the oil film bearings for the back-up rolls of a 5-stands tandem cold mill (installed in 1954) were replaced by the rolling bearings (4-row cylindrical roller bearings). Since then many tandem cold mills built before 1980 have been modified by replacing the oil film bearings with the rolling bearings.

Although, in case of the hot strip mills and the plate mills, the oil film bearings have been mainly applied for the back-up rolls, the rolling bearings in recent years have been increasingly adopted for not only the improvement

of the gauge accuracy but also installation cost.

Figure 2 shows the evolutions of the rolling speeds of typical hot/cold rolling mills and the back-up roll bearings for them.

3. Comparison of Structure between Rolling Bearing and Oil Film Bearing for Rolling Mill Back-up Rolls

Figure 3 shows a typical modified structure for replacing the oil film bearing (Morgoil bearing) with the rolling bearing. The oil film bearing is comprised of a bushing and a sleeve mounted between the chock and the roll, with a Morgoil seal installed on the roll neck. And a double row tapered roller bearing is installed for supporting axial loads.

The rolling bearing (4-row cylindrical roller bearing) consists of outer rings, inner rings and rollers, with a neck seal installed on the roll neck. As the axial support bearing, the same double row tapered roller bearing as used together with the oil film bearing is generally used.

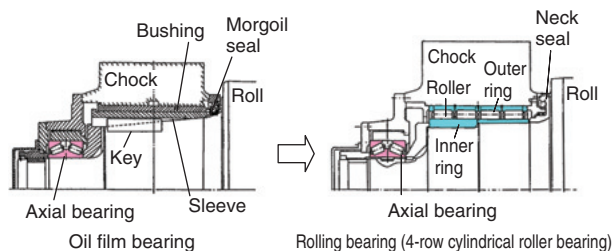


Fig. 3 Replacement of oil film bearing with rolling bearing for back-up roll of rolling mill

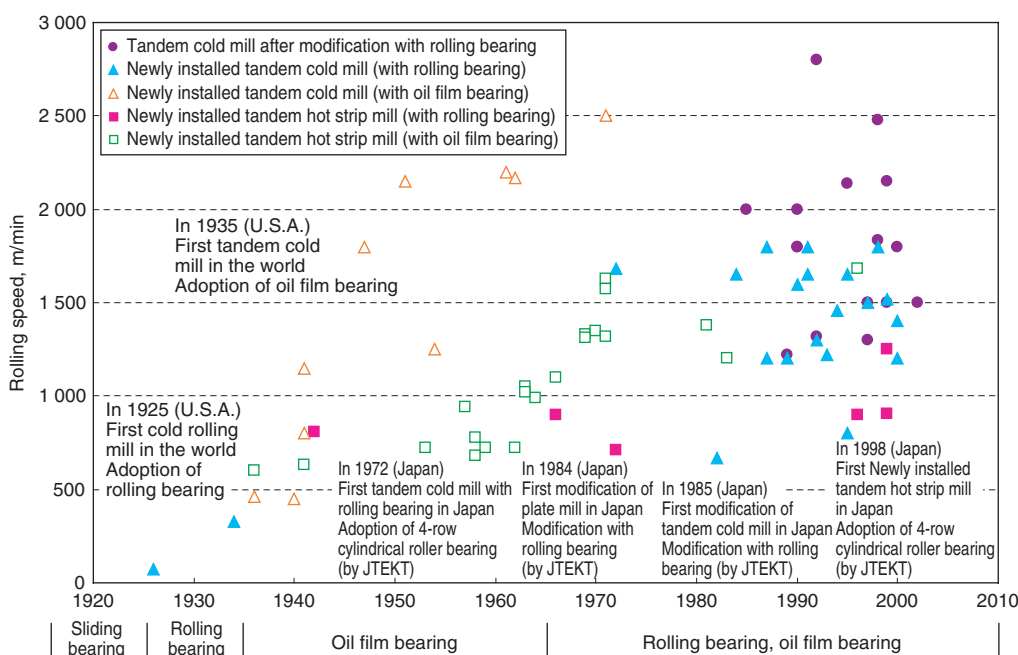


Fig. 2 Evolution of back-up rolls bearings in hot and cold rolling mills

4. Comparison of Performance between Rolling Bearings and Oil Film Bearings

Large differences between the rolling bearings and the oil film bearings in the tandem cold mill are seen in the effects on the gauge accuracy of the rolled products, as shown in **Table 1**, both during the acceleration/deceleration of the rolling and during the steady-state rolling speed due to the difference of the oil film thickness of the bearing as well as the different eccentricity of the bearings.

Table 1 Effects of acceleration, deceleration and steady-state rolling speeds on their gauge accuracy of tandem cold mills

	During acceleration/ deceleration of rolling	During steady-state rolling speed
Rolling bearing (4-row cylindrical roller bearing)	The fluctuation of oil film thickness is a few microns; its influence on the gauge accuracy is small, therefore, taking short off-gauge areas.	By applying integral system grinding to the inner ring raceway, the eccentricity of the bearing itself is virtually eliminated, and it's possible to ensure high gauge accuracy.
Oil film bearing	The fluctuation of oil film thickness is several hundred microns; it significantly affects the gauge accuracy, causing long off-gauge areas.	The gauge accuracy deteriorates due to the eccentricity of the oil film bearing.

Figure 4 shows the comparison of the gauge accuracy before and after the modification of the tandem cold mill with the rolling bearings. The modification shows approximately 40% improvement⁴.

Figure 5 shows the result of a bench test conducted at JTEKT. It shows that the fluctuation of oil film thickness in the rolling bearing due to changes of rotational speed is as low as 3% or less of that of the oil film bearing⁵.

Also, there have been multiple reports from steel manufacturers showing improvements of the gauge accuracy by modification of the back-up roll with the rolling bearings (4-row cylindrical roller bearings), establishing superiority of the rolling bearings.

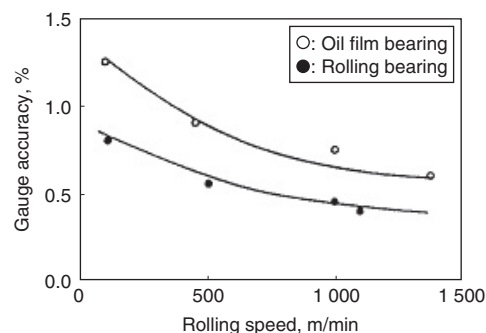


Fig. 4 Improvement of gauge accuracy after applying rolling bearing

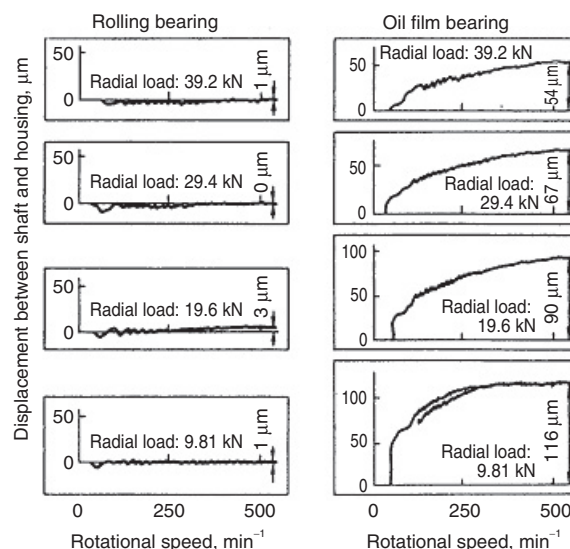


Fig. 5 Displacement between shaft and housing versus rotational speeds

5. Design Approach for Replacement of Oil Film Bearing with Rolling Bearing and Example of Modification

The oil film bearing consists of the bushing and the sleeve installed between the chock and the roll, and in the modification, the bushing and the sleeve are replaced by the rolling bearing.

In this case, the basic constraint is that the existing chock, the roll and the peripheral parts should be utilized as much as possible. Since the steel manufacturer normally keeps spare parts of the chocks and the rolls, producing new parts would drive the modification cost much higher.

Figure 6 shows the design flow chart of the rolling bearing modification with key points.

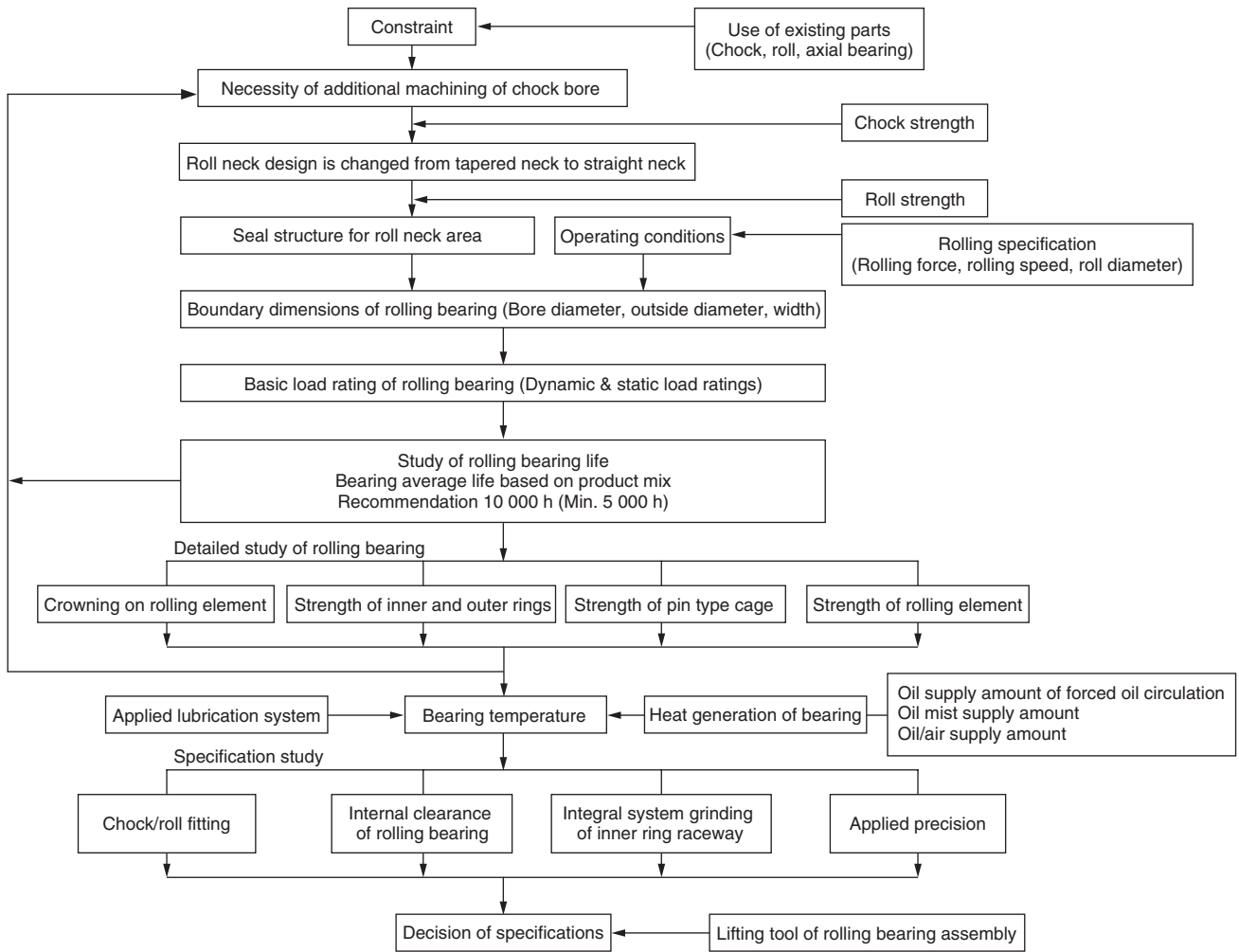


Fig. 6 Design flow chart for rolling bearing modification

5. 1 Modification Design of Chock

- (1) The existing chock should be utilized.
- (2) The requirement for additional machining of the chock bore as well as the machining dimensions should be determined taking into account the chock strength, the direction of mounting and dismounting of the rolling bearing to the chock, and interference with other parts. This is for the purpose of maximizing the outside diameter of the rolling bearing to increase the highest basic load rating possible.

5. 2 Modification Design of Back-up Roll

- (1) The existing back-up rolls should be utilized.
- (2) The machining dimensions on the journal and the neck portions of the roll should be determined based on the study of the rotating bending fatigue strength and the result of FEM analysis (Fig. 7). The roll journal is modified from the taper shape to the 2-stepped shaft (Fig. 3), but the basic load rating of the bearing can be increased if a non-stepped shaft provides sufficient roll strength.

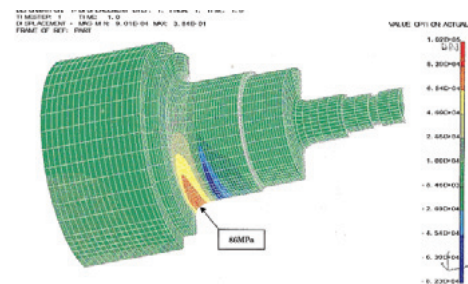


Fig. 7 FEM analysis of back-up roll neck

5. 3 Structure Design of Neck Seal

The structure of the neck seal is very important for preventing early failure of the rolling bearing. Figure 8 shows the structure of the typical neck seal, which consists of two face contact seal lips (scale seal and intermediate seal) and two radial contact seal lips (YSN seal). This neck seal has been in service satisfactorily even on a high-speed rolling mill working at a speed of no less than 2 500 m/min (seal lip speed: Max. 35 m/s). Both seals are the types adaptable to high-speed rolling with their seal surfaces designed for low torque and improved resistance to hardening and wear.

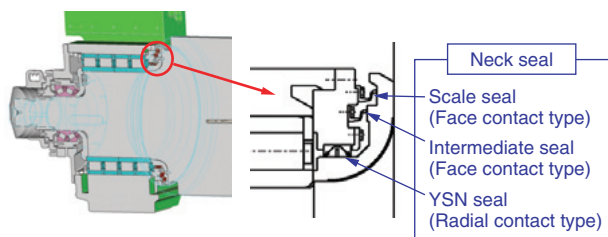


Fig. 8 Structure of roll neck seal

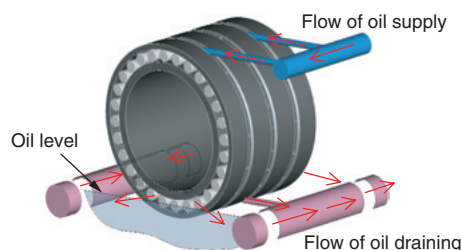


Fig. 9 Flow of in-and-out lubricant

5. 4 Study of Lubrication System

While, in the case of oil film bearings, the forced oil circulation system is the only applicable lubrication system, in the case of rolling bearings, various lubrication systems are available depending on the rolling speeds as shown in **Table 2**.

Table 2 Examples of lubrication systems for rolling bearings

Lubrication system	Guideline of rolling speed (m/min)
① Forced circulation of oil	2 800 ^{*1}
② Oil mist lubrication	1 650
③ Oil/air lubrication	1 650
④ Grease lubrication	500

*1: 2 800 m/min is fastest in the world.

① **Forced oil Circulation Lubrication:** In the case of the modification by the rolling bearing replacement, it is possible to utilize the same lubrication system used for the oil film bearing. Also, in regards to oil film formation on the rolling surface, the lubricant with the same viscosity (ISO VG460, VG220) as that used for the oil film bearing can be used for the rolling bearing. In such cases, though, it is necessary to do additional machining of oil inlet and outlet holes for the rolling bearing as shown in **Fig. 9**.

The oil supply amount to the rolling bearing can be reduced to 1/2~1/3 that of the oil film bearing and bearing temperature can be predicted. Thus, in case of a tandem cold mill, the existing two lubrication systems, each for front stands and rear stands, can be combined into one lubrication system, which also reduces maintenance costs.

② **Oil Mist Lubrication:** This lubrication system has been adopted since the 1970s. In case of the modification by the rolling bearings replacement, as this system was applied to the front stands, the lubrication system could be reduced from two forced oil circulation units to one.

③ **Oil/air Lubrication System:** This lubrication system has been used widely to achieve a cleaner working environment in recent years. JTEKT has developed the oil/air lubrication systems specialized for steelmaking equipment, which have already been adopted on many rolling mills. In the future JTEKT is planning to propose this system in place of the oil mist lubrication system.

④ **Grease Lubrication:** Grease lubrication is useful in cases where the loading condition is not so severe and the rolling speed is not high.

5. 5 Examples of Modification by Rolling Bearing Replacement

Examples of the rolling bearing modification for tandem cold mill are shown as follows. **Table 3** shows the specifications of the rolling bearings that replaced the oil film bearing of the same size (Morgoil bearing: 44 inches). As the result of designing the rolling bearing to minimize the cost and taking into account the operating conditions of each rolling mill, both have achieved satisfactory service life even though these bearings have different boundary dimensions. Also, the neck seals have satisfactory operation without any early failure. These examples show the validity of the modification design.

In **Fig. 10**, the rolling bearings installed on the back-up rolls of tandem cold mills are plotted on the figure based on the rolling bearing thickness ratio, which is the value obtained by dividing the bearing thickness: T by the bearing bore diameter: d.

While the thickness ratios of the rolling bearings on newly installed cold rolling mills show a certain value, those of the bearings for modified cold rolling mills show a widely spread distribution because they have been designed in accordance with the existing rolling specification of individual mills.

Incidentally, as these rolling bearings are very heavy, it is necessary to handle them carefully to prevent any damage. JTEKT also provides a lifting tool for the rolling bearing assembly which facilitates safe installation to and removal from the chock (**Fig. 11**).

Table 3 Example of rolling bearing specification after replacing oil film bearing (44 inch) with rolling bearing

	Example 1	Example 2
	6 stands tandem cold mill (#1~#6)	5 stands tandem cold mill (#5)
JTEKT bearing No.	133FC97732HCS	142FC93635YCS
Bearing boundary dimensions	$\phi 665 \times \phi 968 \times 732$	$\phi 710 \times \phi 930 \times 635$
Basic dynamic load rating, kN	21 200	15 500
Basic static load rating, kN	53 300	47 000
Mass, kg	1 880	1 320
Max. radial load, kN	6 370	3 920
Max. rotational speed, min ⁻¹	658 (dm · n=538 × 10 ³)	470 (dm · n=387 × 10 ³)
Calculated bearing life (Average in all stands), h	Approx. 25 000	Approx. 13 500
Actual bearing life, h	Approx. 30 000 (No flaking)	Approx. 20 000 (No flaking)

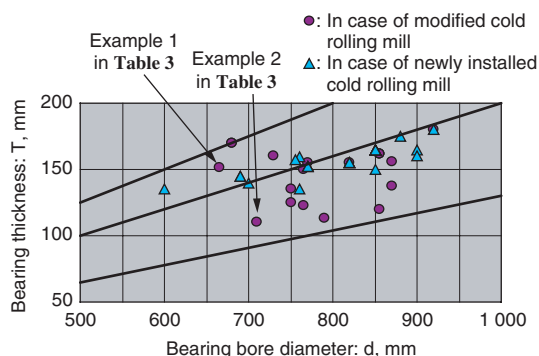


Fig. 10 Comparison between bearing bore diameter and bearing thickness in cold rolling mills

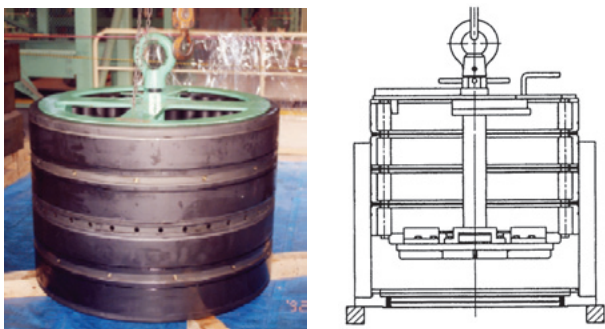


Fig. 11 Lifting tool for rolling bearing assembly

6. Proposal for Future Modification with Rolling Bearings

6. 1 Situation after Modification with Rolling Bearings

The business environment surrounding the steelmaking industry has remarkably changed for the better in recent years. To meet the rapid increase in demand, each steel manufacturer has increased the operation ratio of the steelmaking equipment, especially the rolling mills, with an accompanying increase the rolling force and the rolling speed.

Initially, when rolling mills were modified with the rolling bearings, the bearings that had been designed taking into account the operating conditions of each rolling mill sufficiently satisfied the performance requirements. However, due to increase of the rolling force, the rolling speed and the production volume, the actual bearing life has declined, sometimes causing operational problems (Fig. 12).

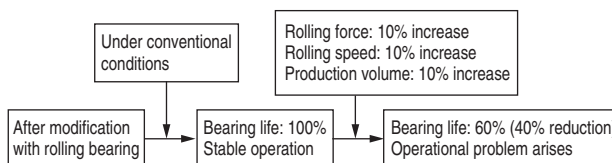


Fig. 12 Decrease of rolling bearing life due to severe rolling conditions

6. 2 Proposal of Rolling Bearing Life Improvement through Re-modification

For improving the life of the rolling bearings by solving the problems mentioned above, it is effective to use a new long-life material and change lubrication conditions. However, in the case shown in Fig. 12, where the bearing life declines as much as 40%, it becomes necessary to increase the basic load rating of the bearing. Usually, to increase the basic load rating, it is necessary to increase the boundary dimensions of the bearing and modify the internal design. In that case, it is required to newly produce not only the bearing but also the chock and the roll, resulting in increased cost of design and manufacture.

In response to such problems, JTEKT has proposed a new re-modification of the rolling mill, as shown in Fig. 13, that could increase the basic dynamic load rating of the bearing with minimum cost of the design and the manufacture. For example, it is possible to obtain a 10% improvement of the calculated bearing life by re-modification compared to the original design even when the calculated bearing life is reduced to approximately 60% of that in the original operating conditions.

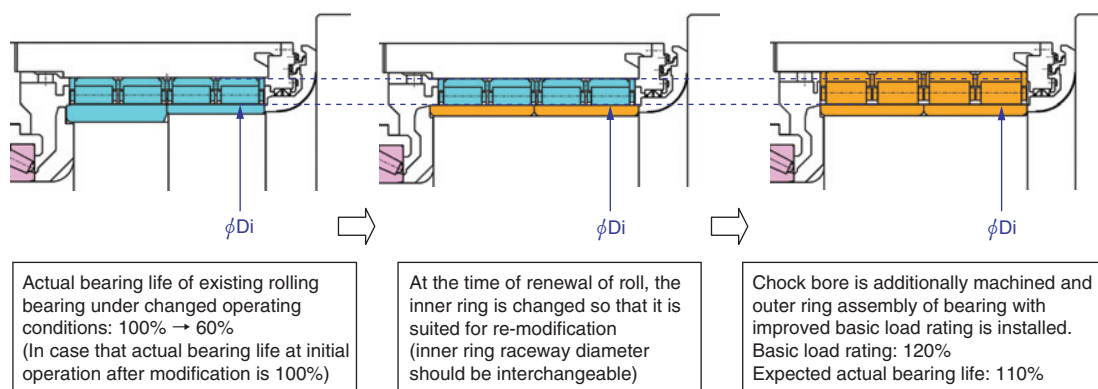


Fig. 13 Proposal for improving rolling bearing life by re-modification

7. Conclusion

Since JTEKT carried out the modification design and delivered rolling bearings for the modification of the plate mill by replacing the oil film bearing of the back-up roll with the rolling bearing in 1984, JTEKT has completed many projects. In these modifications, JTEKT has built not only the excellent delivery history, but also many invaluable engineering procedures.

Through these many experiences, JTEKT has not only contributed to the improvement of the gauge accuracy for the steel manufacturers, but also cultivated the new large market of the rolling bearings. So far, most of these modification projects have been done in the Japanese market. Now it is considered to be time for JTEKT to expand the modification actively in the worldwide market.

Furthermore, through the establishment of the method for the modification with the rolling bearings as presented herein, it has become possible to design the rolling bearings having more adequate performance. In the future, it is considered an effective measure to study the feasibility of applying the rolling bearings to the back-up rolls of hot strip mills which are currently dominated by the oil film bearings. JTEKT will continue to further expand the market for the rolling bearings, and also make efforts on the developments of technology and products to meet the needs of the present.

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