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Establishment of Oil-Air Lubrication System in Continuous Casting Machine

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Abstract:

A large number of bearings are used in the segment of the continuous casting machine. The bearing used in the segment causes troubles frequently due to the severe environment such as extremely low speed of the rotation, higher load and higher temperature. Even one failure of the bearing in the segment causes a replacement of the segment, and entire facilities need to be shutdown. Therefore, as a countermeasure, Oil-Air Lubrication system was introduced for bearing lubrication. In this paper, we describe the breakage mechanism of bearing and the effect of Oil-Air Lubrication system, which is installed in our continuous casting machine.

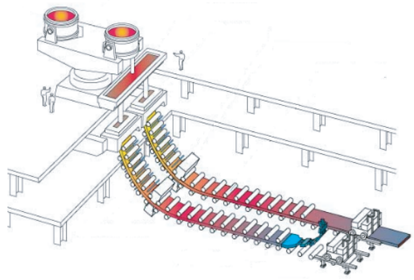

Fig. 1 Continuous casting machine

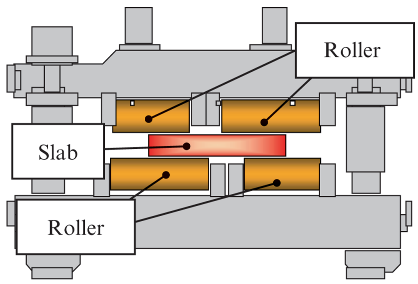

Fig. 2 Segment unit

1. Introduction

In the continuous casting machine (**Fig. 1**) in a steelmaking shop, slabs are cast by pouring molten steel into the mold and then casting the steel while solidifying it in units called segments (**Fig. 2**), which consist of pairs of rolls. Because continuous casting machines operate continuously 24 hours a day, stable operation is demanded.

A large number of bearings, totaling as many as 1 000 or more, are used in the segments. The type of bearing used is the self-aligning roller bearing, as this type has advantages in terms of load capacity and alignment. The bearing rotation speed is extremely slow, being 5 rpm or less, and the bearing load is high, at $C_0/P<7$. Moreover, segment bearings are used in a high temperature environment, as slabs at a high temperature of about 1 000 ˚C pass in the immediate vicinity of the bearings. This is also a steam environment where secondary cooling water is sprayed.

Since segment bearings are used in a severe environment characterized by an extremely slow rotation speed, high load, high temperature and a steam atmosphere, trouble caused by bearings is a never-ending problem. The conventional bearing lubrication method was a grease lubrication system in which grease was supplied intermittently at set time intervals. However, if even one bearing fails, the entire segment unit must be replaced. Because this leads to a shut down of the entire facility and a corresponding loss of production, toughening is required in bearings. To solve these problems, the conventional grease lubrication system was replaced with an Oil-Air Lubrication system, and the effectiveness of this countermeasure was evaluated.

2. Causes of Bearing Failure

2.1 Content of Trouble

Figure 3 shows the number of unplanned segment

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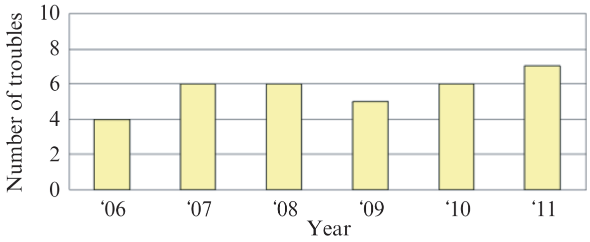


Fig. 3 Number of segment troubles

Photo 1 Broken bearing

exchanges due to bearing-related causes during the past 6 years. As shown in **Photo 1**, flaking occurred on a bearing outer race, and finally the retainer and outer race broke. Because unplanned segment exchanges due to bearing-related causes occurred in 5 to 6 bearings per year on average, and the accompanying production loss also increased in proportion, stabilization of bearings has been demanded.

2.2 Estimation of Factors in Bearing Failure

Figure 4 shows the bearing wear profile and a schematic diagram of the wear mechanism. In self-aligning roller bearings, the diameter of the outer race raceway surface is generally larger than the diameter of the roller, so the circular arcs of the outer race and the roller are not equal. As a result, a speed differential occurs during rolling, except at the two constant velocity points, and those two constant velocity points remain as peaks (non-slip lines) where wear did not occur. In this non-slip line wear, fine cracks are initiated as a result of stress concentrations at the two non-slip lines, leading to flaking[1]. As damage progresses, cracks propagate from the flaking area, causing bearing failure, and the roll rotation becomes impossible. Because scratching of the slab and similar quality-related problems occur, operation cannot be continued in this condition.

Although grease should form an oil film between the outer race and the roller, it can be inferred that the oil film is broken for some reason, and metal-to-metal contact occurs between the outer race and the roller, leading to failure.

2.3 Formation of Oil Film

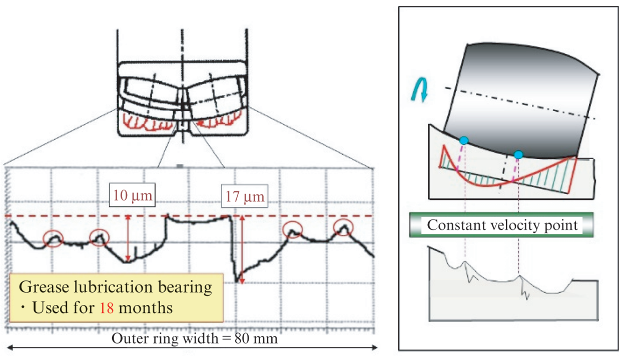
In order to elucidate the factors that cause bearing wear due to destruction of the oil film, it is necessary to investigate the condition of oil film formation and the condition of foreign matters in bearings. First, the condition of oil film formation will be described.

The thickness of an oil film is expressed by the Dowson and Higginson equation[2] shown in Eq. (1). From Eq. (1), it can be understood that the film thickness decreases as the load increases and/or the speed decreases. As mentioned above, in a continuous casting machine, a high load is applied in order to cast slabs, and the rotation speed of the rolls is also slow. Furthermore, this high temperature environment also reduces the viscosity of the oil, and thus is a poor environment for maintaining oil film formation.

$$\frac{H_{min}}{R} = 2.65\frac{G^{0.54}U^{0.7}}{W^{0.13}} \quad \cdots\cdots (1)$$

where, H is the oil film thickness, R is the equivalent radius, G is viscosity, U is speed, and W is load.

Next, the lubrication regions of the grease which is actually used and the oil used in oil-air lubrication were investigated. The oil film thicknesses were measured by using an elastohydrodynamic lubrication (EHL) oil film thickness tester (**Fig. 5**). The measurement method is as follows: A lubricant is coated on the back side of



(a) Wear profile (b) Mechanism of flaking on non-slip line

Fig. 4 Mechanism of flaking on non-slip line

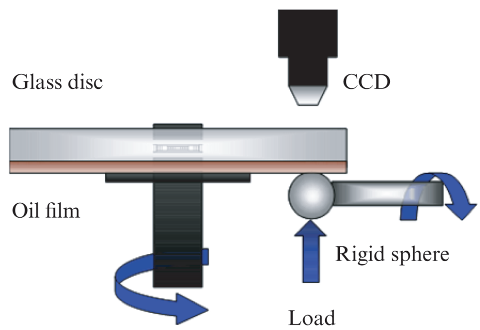


Fig. 5 Schematic diagram of thin film optical method

the glass disc and is placed in contact with the rigid sphere, and the rigid sphere is then rotated. If light is irradiated through the glass disc, an interference film pattern corresponding to the thickness of the oil film is formed by the interference with the light reflected by the rigid sphere surface. The film thickness is measured by measuring the stripes and the spacing between the stripes. Because a load can be applied to the rigid sphere, it is also possible to measure the load dependency of the oil film thickness.

Figure 6 shows the condition of the film thickness by the optical interference film patterns captured by CCD. The calculation results and the film thickness test results are shown in **Fig. 7**. In the continuous casting machine, the film thickness of grease is 50 to 120 nm, while that of oil is 15 to 30 nm.

In the case of grease, the film thickness distribution is not uniform. In particular, the tendency to become nonuniform is strong when sliding is applied. Here, it may be noted that the large film thickness of the grease was due to the increase in thickness resulting from addition of a thickening agent with a urea structure.

In the case of oil, there is no change in the film thickness even when sliding or a change in surface pressure was applied. That is, the results depended only on speed.

The following oil film parameter is known as an index indicating the lubrication region. The oil film parameter Λ is shown in Eq. (2).

$$\Lambda = \frac{H}{\sigma} \quad \cdots\cdots (2)$$

where, Λ is the oil film parameter, H is the oil film thickness and σ is surface roughness.

When the oil film parameter is obtained from the measured oil film thickness, the result for grease lubrication is 0.02 to 0.03. As a lubrication region, this belongs to the boundary lubrication region (Λ<1). The boundary lubrication region is a region where the oil film is remarkably thin, and the thickness of a molecular adsorption film between two solid surfaces that can slide is approximately the size of the molecules. In addition, because local contact occurs between the solids, fluid lubrication theory can no longer be applied. Thus, it was found that the segment of the continuous casting machine is an extremely severe lubrication environment in which oil film formation is inadequate.

2.4 Condition of Foreign Matters in Bearings

To investigate foreign matters in bearings, the grease discharge piping from a segment bearing installed online was extended as shown in **Fig. 8**, and the concentration of iron powder was measured by sampling the discharge grease.

Figure 9 shows the trend of the iron powder concentration in the bearing. The iron concentration was highest immediately after the start of operation, and then decreased and gradually approached about

(a) Grease

(b) Oil

Fig. 6 Thin oil film measurement

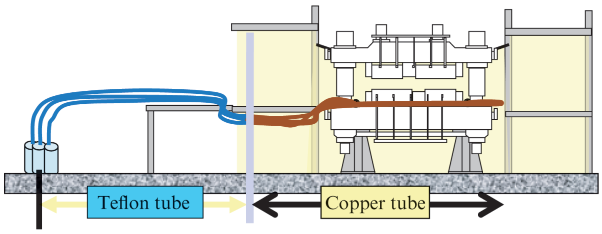


Fig. 8 Sampling system of discharge grease

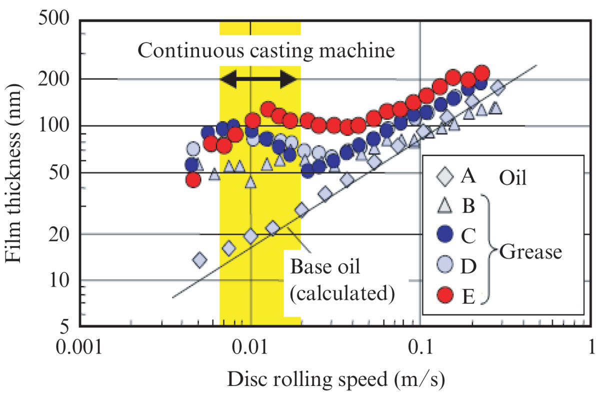


Fig. 7 Relationship between velocity and oil film thickness

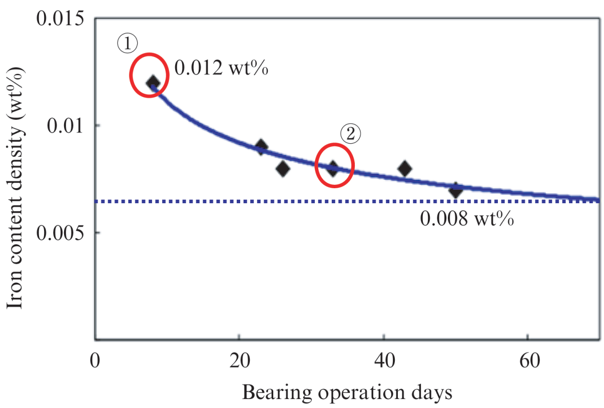


Fig. 9 Trend of iron concentration in discharge grease

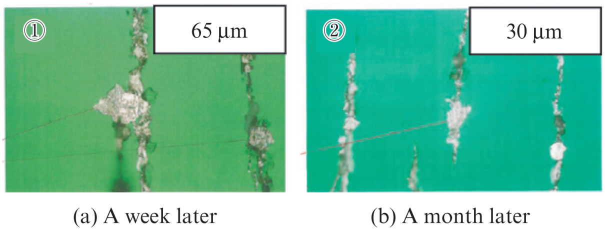


Fig. 10 The analysis of ferrography (Grease)

0.08 wt%.

Figure 10 shows the results of a ferrographic analysis of the grease. The abrasion powder consists of bearing fragments having a maximum size of approximately 65 μm. The morphology of abrasion particles can be classified into two types, i.e., normal abrasion powder and abnormal abrasion powder. However, in this case, it was found that the wear morphology was abnormal abrasion powder.

This result shows that the foreign matter in the bearing is not a substance of external origin, but rather, a self-abrasion powder generated from the bearing itself. Moreover, since the size of the foreign matter was larger than the thickness of the oil film, it is thought that bearing wear was accelerated by destruction of the oil film by this abrasion powder.

2.5 Mechanism of Bearing Failure

As described above, it was found that the foreign matter in the bearing was self-abrasion powder, and the size of the abrasion powder was 65 μm at maximum. Based on these facts, **Fig. 11** shows a conceptual diagram of the bearing wear mechanism. In the bearings in a continuous casting machine, self-abrasion powder is generated inside the bearing under the boundary lubrication condition, and the oil film is broken by this abrasion powder; loss of the oil film accelerates bearing wear, and wear of the bearing proceeds rapidly.

In order to extend bearing life, it is essential to remove the foreign matter inside a bearing and maintain a clean condition in the bearing at all times. Therefore, we examined the Oil-Air Lubrication system, which has excellent cleanliness.

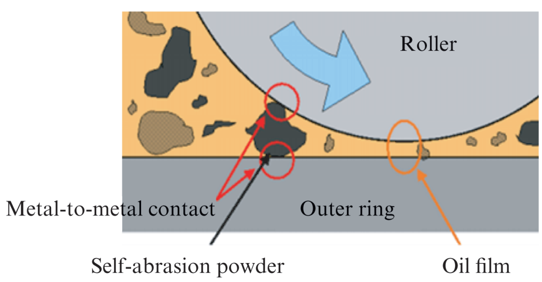


Fig. 11 Conceptual diagram of bearing wear mechanism

3. Introduction of Oil-Air Lubrication System

3.1 Outline of Oil-Air Lubrication System

Figure 12 shows a conceptual diagram of the principle of the Oil-Air Lubrication system. This is a type of centralized lubricating system in which oil is dripped in a passage in the mixing block where compressed air is flowing, and is then transported continuously to the bearing along the inner wall of the tube while retaining its liquid form. This fluid condition in which a gas and a liquid flow through a common passage is called a gas-liquid two-phase flow. In order to supply a constant amount of oil continuously while keeping a liquid form, oil transportation is performed by an annular flow.

3.2 Comparison with Grease Lubrication

Figure 13 shows the comparison of grease lubrication and oil-air lubrication. At JFE Steel, a grease-air system had been adopted in the grease lubrication system. In grease-air lubrication, the grease and air are supplied via separate piping. The grease is input from the bottom of the bearing, and the air is input from the clearance between the oil seal and the dust seal. The grease is supplied at set intervals at a rate of 6 to 10 cc/h. The air is supplied from between the seals and has the effect of preventing intrusion of water and for-

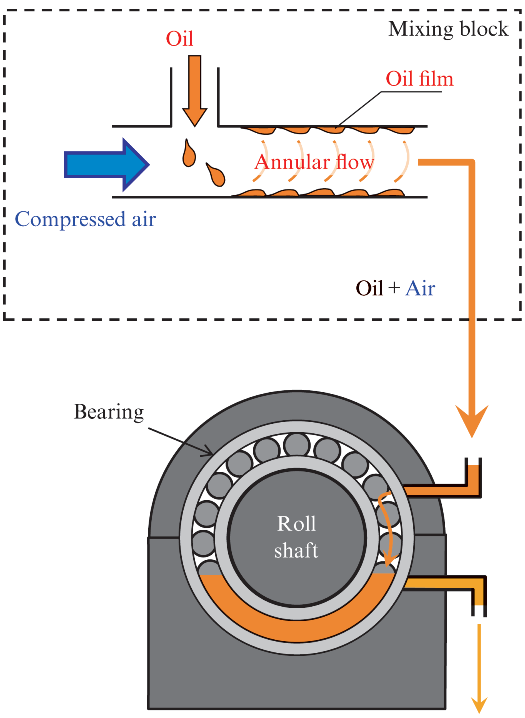


Fig. 12 Principle of oil-air lubrication system

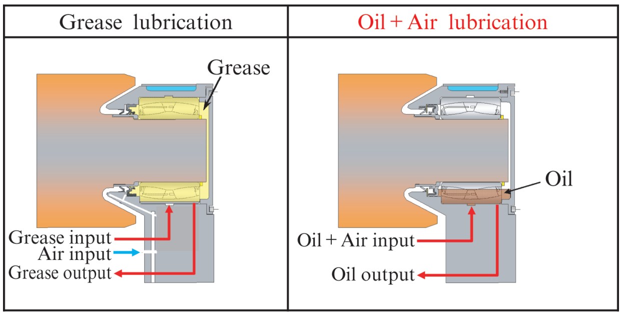


Fig. 13 Comparison of grease lubrication and oil-air lubrication

eign matters.

Oil-air lubrication is a continuous lubrication method, and it is possible to supply fresh oil at all times. The supply rate is 1 to 3 cc/h and can be reduced in comparison with grease. Because oil containing the foreign matters in the bearing is discharged, the internal parts of the bearing are kept in a clean condition. Moreover, since compressed air is supplied to the bearing at all times, the pressure in the bearing is positive, preventing intrusion of water and foreign matters, and a cooling effect can also be expected. Considering these features, the Oil-Air Lubrication system is extremely effective for both bearing protection and improvement of the bearing environment.

3.3 Comparison of Internal Bearing Structures of Oil-Air Lubrication Systems

The internal bearing structure of Oil-Air Lubrication systems can be classified into two types, the seal-out type and the seal-in type.

The seal-out type shown in **Fig. 14** (a) is a structure in which the oil supplied to the bearing is discharged from the seal part in the bearing. Control of the oil-air system is limited to pressure monitoring on the supply side. Because back pressure control in the bearing depends on the seal, the performance of the seal is critical. In addition, it is difficult to detect abnormalities in case an obstruction occurs in the piping downstream from the pressure switch. This inability to control the condition in the bearing can be considered a demerit.

In the seal-in type shown in Fig. 14 (b), oil is not discharged from the seal part, as in the seal-out type, but is discharged from an oil output hole in the bearing, and is then recovered by a recovery tank via the oil discharge piping. As in the seal-out type, the bearing condition is controlled by pressure monitoring on the supply side.

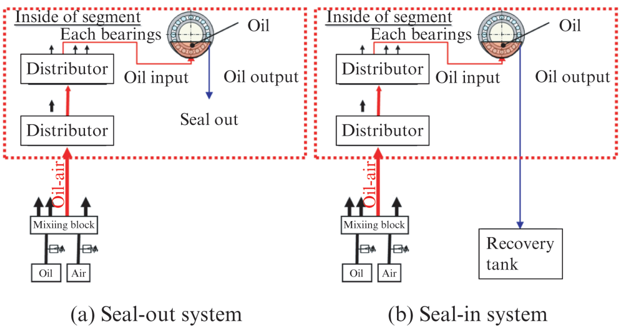


Fig. 14 Seal-out system & seal-in system

3.4 Establishment of Oil-Air Lubrication Control Method

To further improve control of the bearing condition, JFE Steel installed a monitoring panel called a discharge-side monitoring panel (**Photo 2**) as shown in **Fig. 15**.

Photo 2 Monitoring panel

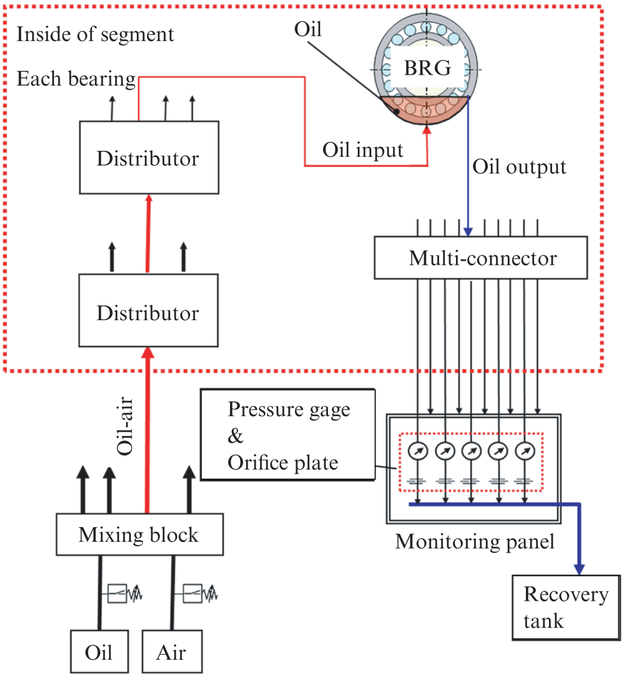


Fig. 15 Oil-air lubrication system

It is possible to control the condition of each bearing from the monitoring panel. Concretely, the condition of the back pressure (pressure) in the bearings can be confirmed from the pressure gauges, and the condition of oil-air return can be checked visually by observing the transparent tubes in the monitoring panel. In addition, because orifices for back pressure control have also been provided, easy exchange is possible, and back pressure control can be performed from the monitoring panel. In addition, the discharge oil can be sampled at the monitoring panel. Thus, the system implemented here enables control of the detailed condition of online bearings, including periodic analysis of iron powder concentration.

If an abnormality is discovered at the monitoring panel, it is possible to take countermeasures in advance, before bearing failure occurs. Various kinds of trouble that could not be prevented by simple pressure monitoring on the supply side can now be prevented, realizing a system that can demonstrate the capabilities of the Oil-Air Lubrication system to the fullest possible extent.

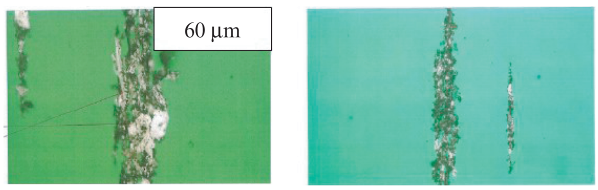
3.5 Actual Machine Verification of Oil-Air Lubrication

In introduction of the Oil-Air Lubrication system, one segment of the grease-air lubrication part was changed to oil-air lubrication, and an actual machine test was conducted. The target segment was a bending zone segment where bearing failure had occurred many times in the past, resulting in unplanned segment exchanges. Normal condition control of the discharged oil was also performed with this Oil-Air Lubrication system by extending the discharge oil piping, as shown in Fig. 8 to create an environment in which the condition of the bearing can be monitored at all times. **Figure 16** shows the trend of the iron powder concentration of the discharge oil in the bearing where oil-air lubrication was introduced. For comparison, the past values during grease-air lubrication in this segment are also shown in the figure.

In the case of grease-air lubrication, there are periods where the iron powder concentration fluctuates drastically. This is thought to be due to the ongoing progress of bearing wear. On the other hand, with oil-air lubrication, the iron powder concentration trends to be on a level about 1/20 of that with grease-air lubrication. It can be said that this is because the iron powder generated in the bearing is removed from the bearing by constantly supplying fresh oil in oil-air lubrication.

Figure 17 shows the result of a ferrographic analysis of oil-air lubrication. Bearing fragments that appeared to be initial-period abrasion powder were found in the analysis one week after the start of operation, and the ferrographic analysis showed that this was normal abrasion powder. In the analysis one month after the start of operation, the abrasion powder had become smaller, and only normal abrasion powder was observed.

Figure 18 shows the results of measurement of the outer race wear profiles of a bearing using grease-air lubrication and a bearing using oil-air lubrication. In the case of grease-air lubrication, the characteristic non-slip line wear pattern of self-aligning roller bearings was remarkable. However, the condition of the bearing using oil-air lubrication was sound, as the outer race showed no conspicuous wear, and non-slip



(a) A week later (b) A month later

Fig. 17 Analysis of ferrography (Oil)

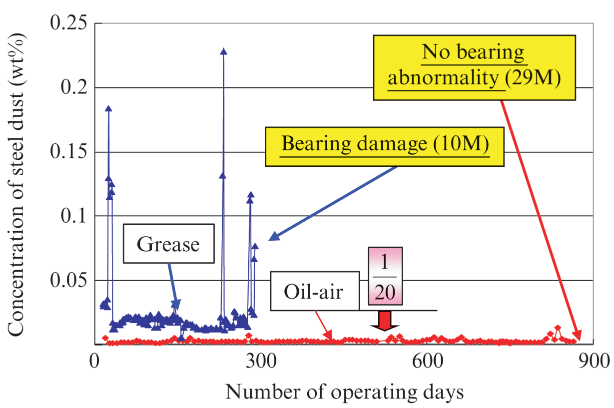


Fig. 16 Trend of iron concentration in discharge grease

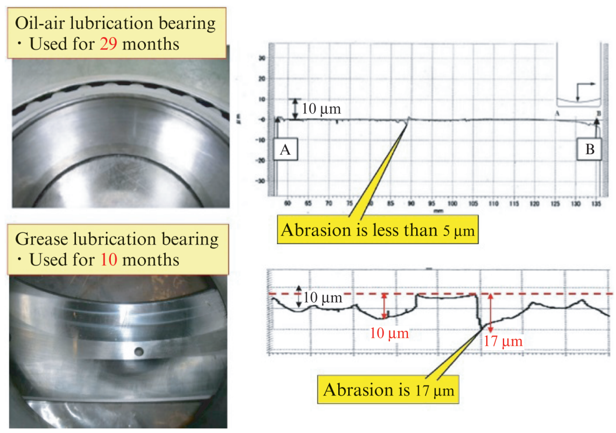


Fig. 18 Wear profile

line wear did not occur.

In addition, in the online period, an abnormality occurred after about 10 months in the bearing using grease-air lubrication, but in contrast, no abnormalities occurred with oil-air lubrication even after use for 29 months. This is the longest record of online use in this segment, and was approximately two times longer that the existing record.

It is thought that the same amount of initial wear occurs regardless of the lubrication method. Since a cleaning effect cannot be expected with grease-air lubrication, the abrasion powder is not completely removed, and some is left in the bearing. The remaining abrasion powder is mixed in the grease, and the grease itself plays the role of an abrasive agent, further accelerating wear. On the other hand, oil-air lubrication excels in cleaning ability, as can be seen from the iron concentration trend and the results of the ferrographic analysis, and that effect contributes to maintaining oil film formation, leading to long bearing life.

As a result of the online actual machine verification, it was found that oil-air lubrication is effective for realizing long bearing life because destruction of the oil film in bearings is prevented, thereby reducing bearing wear. This is possible because a positive pressure can be maintained and the internal parts of bearings are cleaned by constantly supplying fresh oil.

4. Conclusion

A study leading to introduction of an Oil-Air Lubrication system in the segments of a continuous casting machine was described. The results may be summarized as follows.

(1) The mechanism of segment bearing failure was clarified. Specifically, oil film formation is inadequate due to the extremely low bearing rotation speed, high load, high temperature and steam atmosphere. With conventional grease lubrication, wear by self-abrasion powder proceeds due to the inferior bearing cleaning capacity of this technology.

(2) When oil-air lubrication was introduced in a segment bearing, bearing wear decreased, and the life of the bearing was approximately two times longer, verifying the effectiveness of oil-air lubrication, which excels in cleaning performance.

(3) In control of oil-air lubrication, it was possible to control the condition of each bearing by installing a monitoring panel on the oil discharge side. By detecting abnormalities, this system makes it possible to prevent trouble in advance and demonstrate the capabilities of oil-air lubrication to the fullest possible extent.

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