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Stable Operation and Life Extension of Equipment Based on Lubrication Technology

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Abstract

Lubrication is a fundamental technology for the operation and maintenance of all machinery and equipment. In the steel plant, stable operation is supported by many years of daily lubrication management by the collaboration work of lubrication technology department, operations and equipment maintenance personnel, such as lubricant selection, improvement by oil cleanness, life expansion and trouble cause analysis. Particularly in the field lubrication activity, appropriate daily management, improvement and development of lubrication technology for conservation of maintenance load. In this article the achievements by the various improvement measures of lubrication technology and lubrication management will be introduced along in the actual case of steel plant.

1. Introduction

Lubrication is a fundamental technology for all machinery equipment to be operated, and it can be said that that lubricant is one of the essential parts of machinery equipment. In steel works, all concerned persons in the operation division, maintenance division, and lubrication technology/management division are engaged in lubrication and supporting stable operation and production.

Because the condition of lubrication greatly influences the state of operation and life of machine elements, the activities that grasp the state and solve the problem are very important; therefore, in steel works, such activities have been conducted for a long time. Stated here are the stable operation and prolonged life achieved by the condition-monitoring technology and the development of lubricant based on wear particle diagnosis, which enables grasping of the state of machinery accurately at an early stage.

2. Equipment Maintenance and Lubrication Technology & Lubrication Control Structure and Assignment in Iron and Steel Works

2.1 Progress of equipment maintenance system and structure in steel works

Sophistication of equipment maintenance has been sought for in steel works to comply with the growth of complexation in equipment, the continuity in the production process, and the performance, which is growing higher to comply with higher quality & productivity. In addition, almost simultaneously, owing to the evolution of maintenance philosophy and the advanced condition-monitoring technology supported by the equipment diagnosis technology, an advanced system was introduced to the maintenance strategy, and it has been incorporated in the maintenance work in the entire steel works.

As shown in **Fig. 1**, a strategy has developed from breakdown maintenance (BDM), in which a broken machine is repaired, to preventive maintenance, in which preventive work is performed within an appropriate period before a problem occurs. Furthermore, condition-based maintenance (CBM), in which the condition of an equipment is grasped quantitatively and an appropriate measure is taken at an appropriate timing, has come to be practiced. In recent years, maintenance of a proactive concept is also being applied as stated in below examples, wherein the mode of deterioration of the equipment (damage) and its cause are clarified and the deterioration is controlled and suppressed fundamentally by applying maintenance measures retroactive to the cause.

Note that the same maintenance method can be applied to all equipment elements; maintenance methods are practiced by combining each method depending on the extent of seriousness of risk, cost, and appropriateness of management in practical implementation.

2.2 Maintenance structure and assignment in lubrication control

In lubrication control activities, the concept of abovementioned proactive maintenance can be said to be a technological element, which can be practically applied with ease in lubrication control ac-

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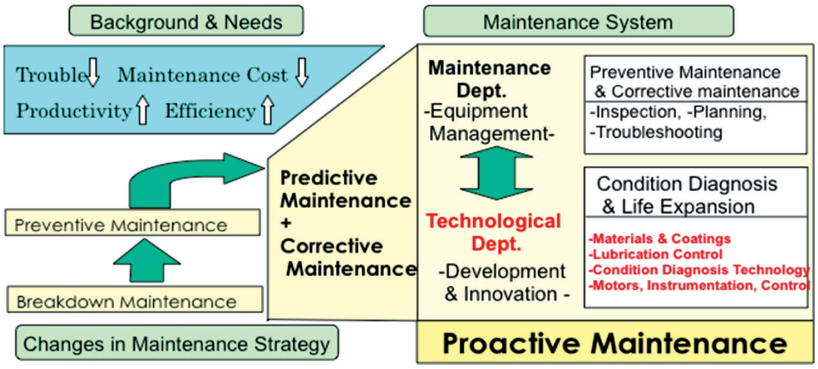


Fig. 1 Change of maintenance strategy in steel works

tivities, because the maintenance includes the lubrication system diagnosis technology, which can grasp the equipment deterioration mode at an early stage and allow relatively labor-saving countermeasure means of changing lubricant to the one having a higher performance or for contamination measures. Practically, it can be the activity that yields fruition in actual fields through extensive technical study rendered by the collaboration work of operation, maintenance, and technical divisions.

Figure 2 schematically shows the summary of desired functions of the structure of the lubrication technology and lubrication control. To apply the lubrication control and lubrication technology to maintenance of equipment so that they can realize fruitful results such as those required by proactive maintenance, fulfilment of assignments, as described in the figure, is sought for under the collaboration of operation/maintenance divisions and technical division; assignments are basically classified into three categories:

(1) In the field activities of operation/maintenance divisions, daily control involves the supply of oil/grease, control of lubricating oil level and quantity, sampling of oil for analysis, and other maintenance items indispensable to daily stable operation of equipment. In addition, when a problem occurs, trouble shooting and providing the solution are conducted by the collaboration of the maintenance division and maintenance technical division. Daily maintenance concerning lubrication is characteristically performed by persons from various divisions, regardless of operation or maintenance. Furthermore, the technical division conducts analysis of sampled lubricating oil, diagnosis, and troubleshooting as well as comprehensive application of the countermeasures across divisions and/or fields. Education of persons from various divisions is also an important assignment.

(2) In field activities, lubrication diagnosis includes monitoring of oil level, oil quantity, and other conditions of lubricating systems in addition to periodical lubricant analysis. The technical division conducts the following: support of such activities by conducting periodical lubricant analysis and operating the PDCA cycle to cope with the situation, development of an additional lubricating system diagnosis technology represented by wear particle analysis, study on application thereof to fields, study on the technology and method of quantitative condition monitoring of equipment by means of the diagnosis method, and provision of the results of the study to fields.

(3) Improvement in problem prevention is promoted in the following manner. When problems occur, they are extracted from the result of trouble shooting, taking into account as reference the result of daily analysis of lubricating oil. Then, the technical division works out countermeasures for field activities based on the study to improve the performance of lubricants (selection or development of optimum oil) and countermeasures for contamination (cleaning). Following this, the follow-up of the outcome is performed. Finally, they are incorporated into control criteria and standards, daily control, and expansion to other fields.

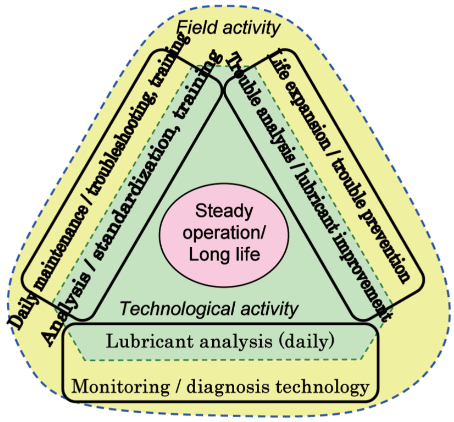


Fig. 2 Structure and function of lubrication management

In steel works, lubrication control is established from the three aforementioned viewpoints based on the activities of a number of concerned persons, regardless of division under the integrated field activities and technical activities.

3. Examples of Improvement by Means of Lubricating Technology

3.1 Lubrication diagnosis technology (wear particle diagnosis technology)

Stabilization of operation of machinery equipment and extension of service life of parts have been realized by optimization of and improvement in lubrication wherein the equipment diagnosis technology of the lubricating system has played a very important role. **Figure 3** schematically shows various diagnosis technologies for the case of condition diagnosis of a bearing lubrication diagnosis. Because lubrication diagnosis is applied to the lubricant circulating through sliding portions, which become the origin of deterioration of machinery and other troubles on account of wearing, it is a diagnosis technology that can notice direct information such as blood inspection without disassembly.

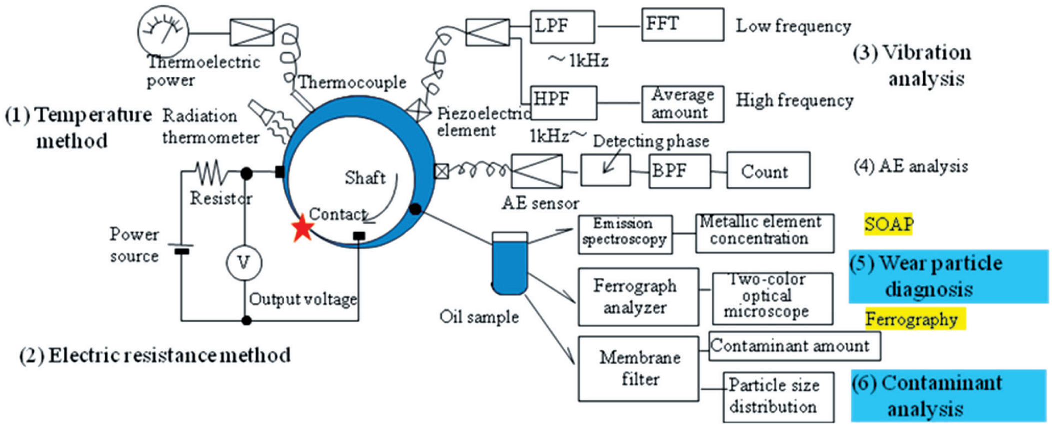


Fig. 3 Schematic of several condition diagnosis method

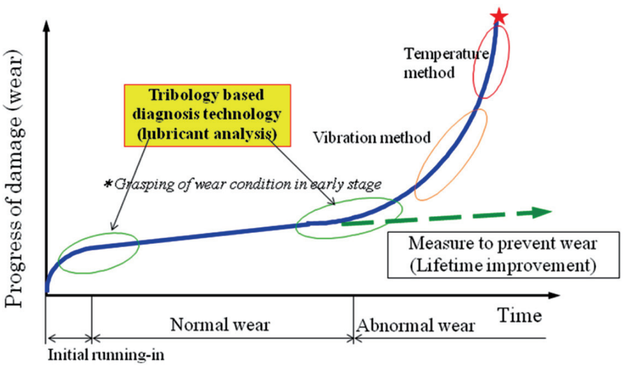


Fig. 4 Progress of damage and failure in machinery

Furthermore, the wear particle diagnosis technology represented by ferrography in particular is an effective method that enables grasping of signs of an abnormal condition at a very early stage because, compared with other diagnosis methods, the form, size, and concentration of wear particles represent the condition of the sliding surface of a machinery element before reaching a state of macroscopic damage due to lubrication trouble of the machine. **Figure 4** shows an image of abnormality-detecting capability of lubricant diagnosis analysis in the time series change in deterioration of general machinery.

Figure 5 shows the principle of ferrography. Soon after being introduced in the early years of 1970s in the UK and USA, Nippon Steel & Sumitomo Metal Corporation introduced the technology to field equipment in the latter half of 1970s. Because it was just the time when the technology came to be used for the research of tribol-

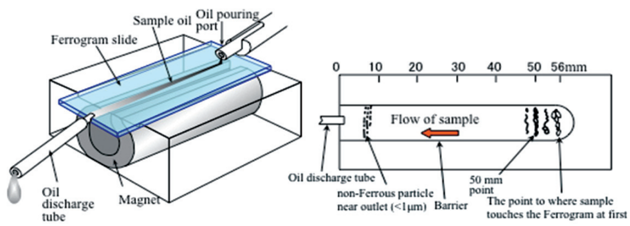


Fig. 5 Principle of analytical ferrography

ogy and for military affairs and no knowhow for industrial machinery was available, data were compiled by the company itself.

The purpose of this technology in not to diagnose the state of lubricant itself; however, with this, the basic strategy has been changed to the proactive control of positively tracing the cause of a trouble for improvement by grasping the condition of machinery through lubricant. The strategy realized the fruition of stable equipment operation and prolonged service life by enhancing lubricant performance and measures for contaminants.

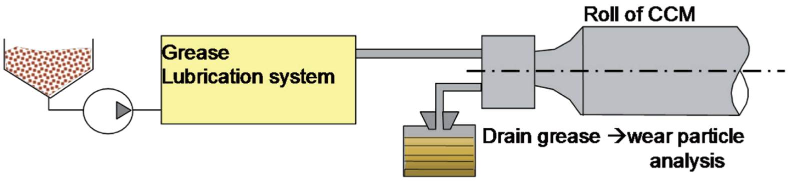
Thus, it can be said that the advantageous features of the lubrication diagnosis represented by wear particle diagnosis are free from the influence of external disturbance and the capability of grasping the sign of damage in an early stage as the information of the condition of the sliding portion of machinery can be obtained directly.

3.2 Outline of fruition obtained with improved lubrication

In certain steel works, as a result of continuous improvements, fruition, as shown in **Table 1**, has been realized with the development of lubricant and measures for contaminant control (elimination of alien substance in oil) together with the effect of oil leakage prevention measures, which will be stated later.

Table 1 Fruitful result of lubrication control (example)

Items	Content of development	Effect
Energy saving	• Development of energy-saving type high performance gear oil • Development of high VI synthetic lubrication oil	Electric power saving 570 million yen/year
Reduction of maintenance cost	• Development of high performance urea grease • Development of various type of high performance lubricant • Measures against contaminant (development of oil cleaner, etc.)	Reduction of parts repair work cost 410 million yen/year
Reduction of lubricant consumption	• Development of high performance lubricant • Activity for preventing oil leakage	Reduction of purchases for lubricant 1 500 million (accumulated from 1977)



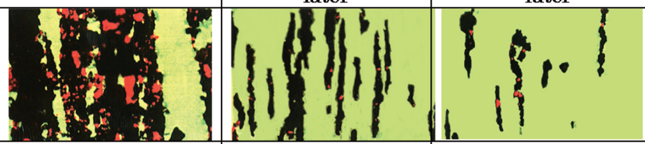
Grease	Lithium-based EP Grease		Urea Grease
Time from change of grease	-----	2 Months later	10 Months later
Ferrography / Wear particle			
AL	Average 62%	Average 24%	Average 10%
Bearing replacement ratio	48%	-----	10%

Fig. 6 Development of grease for CCM roll bearings

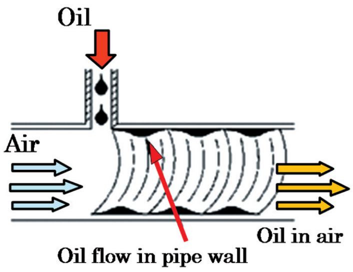


Fig. 7 Principle of oil-air lubrication

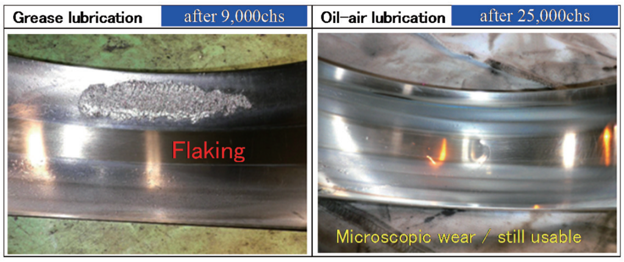


Fig. 8 Result of oil-air lubrication system application to CCM

3.3 Example of improvement in lubrication

Technical contents of several examples of improvement in lubrication, which realized fruition actually, are introduced.

3.3.1 Example of improvement in lubrication

(1) Prolonged service life of bearing of continuous casting machine

Figure 6 shows the example of realizing the effect of the change of the grease of the continuous casting machine roll bearing from the conventional lithium thickener to the high performance urea thickener made with wear particle diagnosis by ferrography. Grease was gradually replaced with the developed grease by supplying it to the centralized greasing system, which had been filled with the conventional grease. As found from the photo, the amount of wear particle after an elapsed time (AL in the figure signifies the concentration of the wear particle) has been greatly reduced and the abnormal wear particle such as a large flat-shaped particle has disappeared. Along with this, the frequency of exchange of bearings at the time of shutdown maintenance of the segment of a continuous casting machine has decreased significantly.

Furthermore, in recent years, oil–air lubrication, as shown in **Fig. 7**, is being adopted to the continuous casting machine bearing. In the oil–air lubrication, intrusion of dust and/or water from the surrounding can be prevented by maintaining the inside pressure of the bearing box at a constant pressure. Furthermore, because lubricating oil of a higher viscosity is usable in comparison with grease lubrication, it is an effective measure for improving and prolonging the service life of low-speed and high-load continuous casting machine bearings. **Figure 8** shows the states of the bearing raceway surface before and after actual application of an oil–air lubrication system. In conventional grease lubrication, it is observed that after the service of 1 year 9000 charges, wear of the rolling contact surface is large and flaking has developed partly. In contrast, after changing to oil–air lubrication, wear of the rolling contact surface has become small even after the service of 25000 charges, larger by three times (less than 1/2 of before), and a great life-prolonging effect is noticed.

problem	solution
Abnormal wear containing water	High performance grease, seal
Abnormal wear by contaminant	Oil seal design (anti- water/solid)
Life extension against bearing fatigue	Development of bearing material/ heat treatment

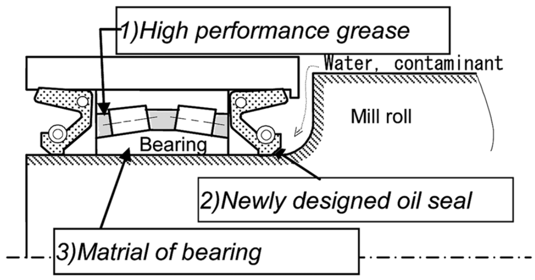


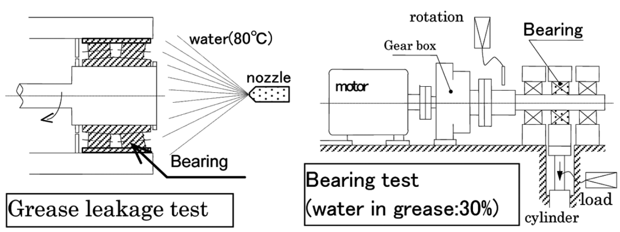
Fig. 9 Reliability improvement for mill roll-neck bearings

(2) Prolonging rolling mill roll neck bearing life

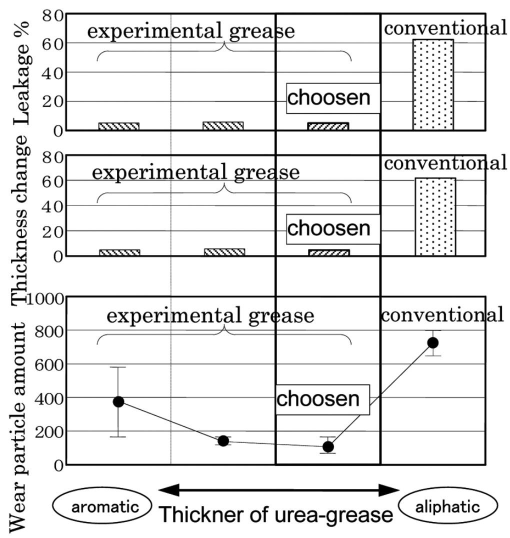
Figure 9 shows the measures for enhancing rolling mill roll neck bearing reliability and prolonging service life. Most roll bearing manufacturers mainly work on the issues of designing and material improvement of bearing. In addition, with regard to lubricant (grease) suppliers and oil seal manufacturers, in most cases, they work on the issues of optimization in their own part of the jobs. Then, they also conduct appropriate measures to meet conditions by exploring the actual state of machine using the abovementioned lubrication system diagnosis technology.

Figure 10 explains how the grease that most suits this usage has been developed. Compositions are optimized on the basis of urea grease, and the optimum point where the bearing service life is stabilized and the influence of water contained on the change of grease property is minimized is found. **Figure 11** shows the result of assessment of the application of grease to the work roll bearing of the finishing mill of a hot rolling mill. The result of wear particle diagnosis shows the reduction of wear particle concentration to half.

Practically, prolonging the work roll bearing exchange cycle by 1.5–2.0 times will become feasible.



(a) Test methods for grease evaluation



(b) Test results

Fig. 10 Development of roll-neck bearing grease

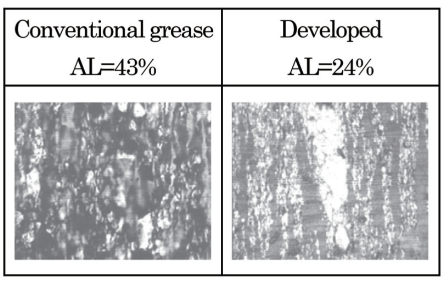
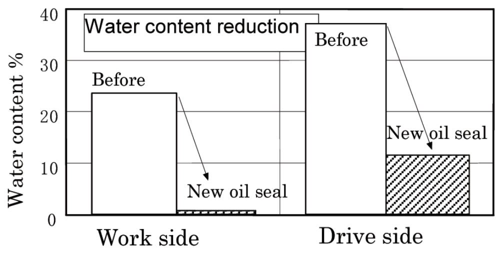


Fig. 11 Result of HRM finishing mill roll application

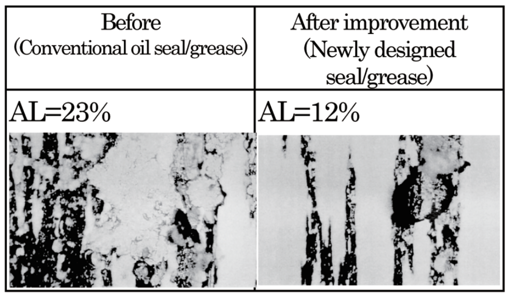
Figure 12 shows an example of improvement in the oil seal of a cold rolling mill. As a result of improving the shape of an oil seal lip and thereby prolonging sealing service life and improving the followability to the displacement of the roll axis, water content after the completion of an actual operation drastically decreased and wear particle of the bearing was nearly halved. Therefore, the work roll exchange cycle has been prolonged by approximately 1.5 times.

3.3.2 Stable operation of hydraulic equipment with contaminant control

Figure 13 shows an example of effective implementation of

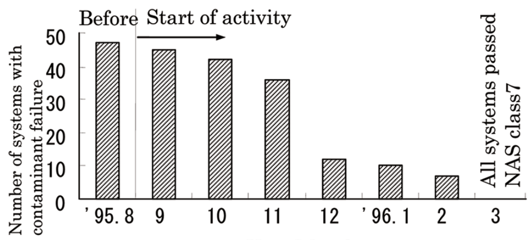


(a)Water content of sample grease

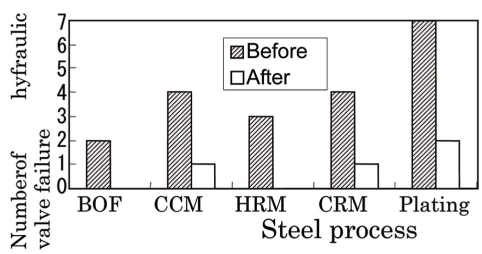


(b)Comparison of wear particle (Ferrography)

Fig. 12 Effect of new oil seal in cold mill roll



(a) Number of contaminant failure in servo systems



(b) Number of failure in hydraulic valve

Fig. 13 Result of contaminant control in servo-hydraulic system

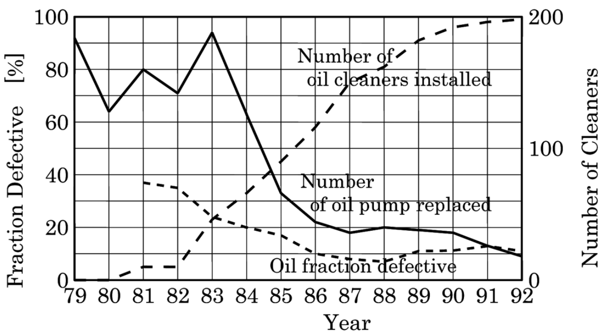


Fig. 14 Result of contaminant control activity in steel works

contaminant (alien substance in hydraulic oil) control in servo hydraulic systems.

The contaminant control criterion of important hydraulic equipment such as a servo system was set at NAS 7 class, and oil-cleaning measures were conducted simultaneously. In the figure, as shown in the above graph, equipment with contaminant failure has gradually decreased and almost disappeared. In the lower graph, to show the effectiveness, comparisons of the numbers of operation failures in respective process before and after the activities of the contaminant control are shown, and it is shown that operation failures have decreased significantly and the countermeasures have effectively contributed to the stable operation of equipment. As a result of the oil cleaning measures, as shown in **Fig. 14**, reduction in the number of sliding parts exchange of oil pumps owing to reduced wearing, namely effects on reduction in cost, has been noticed.

3.4 Measures for enhancing equipment reliability of lubrication–hydraulic system

Examples of fruition of improvement by mainly enhancing the performance of lubricant have been introduced above; however, it is also important to prevent the problems and improve equipment reliability from the viewpoint of management of the field maintenance activities.

In the field activities of lubrication control, in the first stage, oil leakage control activities were conducted wherein target values of oil consumption (HFI: yearly oil consumption quantity divided by oil tank capacity) were set, the reduction in oil and grease cost by improving oil seal and packing (service life extension) and preventing weld cracks in piping was achieved, and the foundation for appropriate lubrication diagnosis was simultaneously established. This is because if a large amount of oil supply is required owing to leakage, lubrication diagnosis would become meaningless. It can be said that improvement in the lubrication system and service life extension have not become possible without the aforementioned management.

Based on the continuous activities since the past, activities aimed at further stabilizing equipment operation are being conducted at present. For instance, in designing lubrication– hydraulic equipment, a maintenance prevention (MP) design is oriented utilizing the experience of past troubles; this method is also standardized. Structures of tanks, distance between clamps of piping, types of actuators, selection of materials, and so on are prescribed.

In addition, based on findings in maintenance activity, further measures for a hydraulic–lubrication system contributing to stable operation are conducted. **Figure 15** shows, for the case of a hydraulic system, the illustrated summary of measures contributing to stable operation. In the measures for contaminant control, a flashing

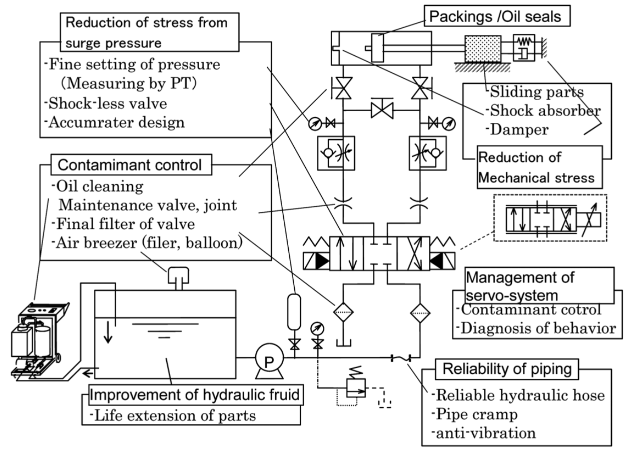


Fig. 15 Total reliability improvement of hydraulic system

circuit, which replaces the oil inside of the piping, and a preventive device for intrusion of contamination from the air breezer are installed in addition to an oil cleaner. To reduce the influence of surge pressure, comprehensive measures of installation of a dumper at the stroke end of an actuator, selection of the optimum pipe clamping, selection of an optimum hose and its control of exchange, and enhancement of performance of hydraulic oil, all contributing to stable operation, are provided.

4. Conclusion

Owing to a good collaboration of concerned persons of the lubrication technology and field lubrication control, an obvious result of reduction in cost realized by stable operation of equipment and prolonged service life has been concretely confirmed. One of the principal factors of fruition is the function of the lubrication system diagnosis technology, which can grasp the abnormalities of machines at an early stage without any external disturbances.

Hydraulic–lubrication systems are widely and commonly used machineries not only in iron- and steel-making process but also in many other fields; therefore, such improvements should be expanded across fields to obtain fruition in a wider region. For instance, in the case of developing a lubricant, assessment takes a long time by comparing its performance and or its damage after a maintenance period is completed. However, if wear particle diagnosis is utilized, the development and assessment can be accelerated and man power can be remarkably reduced as the concentration of wear particle and the condition of lubrication (existence or nonexistence of an abnormal wear particle) can be assessed at the very early stage after the start of trial use. As shown in **Fig. 16**, improvement and development can be effectively promoted, and it can be said that the greatest advantage of the lubrication technology and control is the realization of merits in actual machines at an early stage.

In recent years, because the load on steel-making equipment has become much higher, it is anticipated that the influence of long-term damage on machineries will be actual, and from now on, the author is expecting continued efforts for stable operation and enhancing functions of equipment by solidifying the foundation of the lubrication technology and lubrication control with further emphasis on efforts to inherit the technologies.

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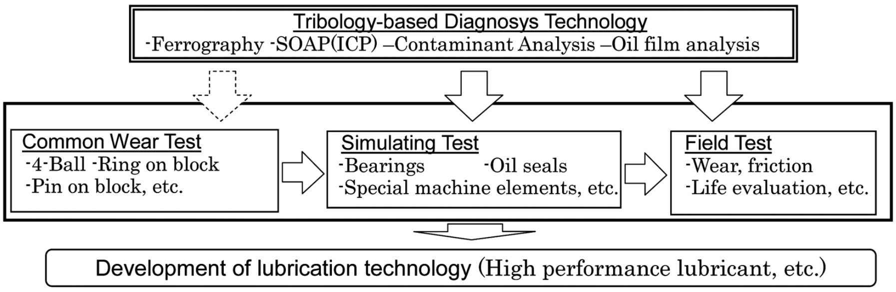

Fig. 16 Effective development system in lubrication technology utilizing tribology-based diagnosis method

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