CBM Life Cycle Maintenance

— Marine Equipment Condition Monitoring and Evaluation Technologies —

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1. INTRODUCTION

IACS Unified Requirement (hereinafter, UR) Z27 specifies the scheme for certification of Condition Based Maintenance (hereinafter, CBM), and it is implemented uniformly in IACS from January 2020. In line with this UR, ClassNK also began full-scale promotion of CBM certification. Because CBM technologies enable remote monitoring, assessment and prediction, these technologies are needed in fields with a high demand for automation. The benefits of application CBM to can be summarized as follows:

1) Optimization of maintenance
   Monitoring of the degree of deterioration makes it possible to identify locations that require maintenance, thereby leading to reductions in the burden and cost of surveys.
2) Rationalization of surveys
   Some parts may last longer than the predetermined survey interval, while others may develop abnormalities before the next surveys. Stable survey that is according to the operating condition of each equipment can be achieved by CBM.
3) Standardization of surveys
   Because surveys tend to depend on the experience of surveyors, variations in survey accuracy may occur. Standardization of evaluation techniques based on quality-assured sensor data can easily enable uniform survey comparable to that of skilled surveyor.

However, while CBM practices provide the above benefits, challenges also remain:

1) Initial and running costs
   Installation of sensors and analysis instruments increases the initial cost, and the cost of maintaining that equipment also increases. In particular, monitoring via ship-shore communication requires consideration of additional cost, like communication costs and monitoring cost etc.
2) Reliability of measured values and analysis methods
   Without application at appropriate locations within the range in which sensor accuracy is guaranteed, the results will lack reliability. Therefore, appropriate measurement method and an analysis method for the measurement results are essential.
3) Acquisition of judgment criteria
   Seafarers and surveyors must possess the knowledge to identify data configurations that are judged to be anomalous and determine whether survey is necessary or not.

Because CBM is positioned as an important step toward developing advanced automated and autonomous ships in the future, advancement of onboard data accumulation technologies and technologies related to sensor accuracy is foreseen. Accordingly, the NK Research Institute also expects a further expansion of CBM applicable ships, and will proceed to develop rational equipment monitoring and analysis methods and revise and establish the relevant rules.

2. CBM RULES OF ClassNK

In adoption of CBM for marine equipment, the open-up examinations in Table 1 can be performed based on the CBM Scheme upon application by the shipowner (ship management company) and approval by ClassNK:

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Table 1 Open-up Surveys of Machinery and Equipment

Items	Examinations
1. Reciprocating internal combustion engines	- Cylinder covers, cylinder liners, pistons, crosshead pins and bearings, connecting rods, crank pins and bearings, crank journals and bearings, camshafts and camshaft driving gears, turbo chargers, scavenge air pumps or blowers, air intercoolers, attached essential pumps
2. Steam turbines	- Turbine rotors together with bearings, turbine casing, turbine and reduction gear couplings, nozzle valves and maneuvering valves
3. Power transmission systems and shafting systems	- Reduction gears, reversing gears, clutch gears, flexible couplings, intermediate shafts, thrust shafts and their bearings
4. Auxiliary engines	- Auxiliary engines driving generators, auxiliary machinery essential for main propulsion and auxiliary machinery for manoeuvring and personnel safety
5. Water jet propulsion systems	- Hydraulic pumps for steering actuating systems, lubricating oil pumps, coolers, etc.
6. Azimuth thrusters	- Gears, gear shafts, shaft couplings, bearings and clutches for propulsion and for steering, hydraulic pumps and hydraulic motors, lubricating oil pumps, coolers, etc.
7. Auxiliary machinery	- Air compressors, blowers, cooling pumps, fuel oil pumps, lubricating oil pumps feed pumps, condensing pumps, drain pumps, bilge pumps, ballast pumps, fire pumps, condensers, feed water heaters, coolers, oil heaters, fuel oil tanks, air reservoirs, cargo piping systems, deck machinery, distilling plants, etc.

Application of CBM is possible to an overall equipment basis or an individual part basis. The final decision on adoption is made based on factors including administrative costs, the degree of burden on seafarers and technological potential. ClassNK has also established PROCEDURES FOR THE APPROVAL OF PMS/CBM MANAGEMENT SOFTWARE (Annex B9.1.3-4). In 1.3.3-1(3), Annex B9.1.3-4, these Procedures require that measurement data trends and limit values be exhibited for diagnosis of operating conditions to ensure equipment safety. However, determining condition anomalies is extremely difficult given the complicated parameters involved, such as engine load and performance, weather conditions and other external factors and fuel properties. Accordingly, the key points for implementation of CBM include efforts to pursue reliability, data accumulation and effective use to suit anomaly detection technologies developed by the equipment manufacturers and corporate shipowners (ship management companies) concerned.

3. ABOUT THE PRESENT STUDY

The present study is joint research conducted on the basis of the above items by a corporate shipowner, an equipment manufacturer and a classification society aiming at “damage assessment by main bearing Lubricating Oil (hereinafter, LO) outlet temperature monitoring” toward CBM implementation. The results have been incorporated in ClassNK’s CBM Guidelines (Ver. 2.0).

In this study, we grasped where and how failure occur in ship’s main engine plants, what effects failure have, and what to do on the ship to prevent that, and a risk assessment method was used to examine alternative methods that conventional methods are replaced by the data monitoring methods. This risk assessment method uses Fault Tree Analysis (FTA) to analyze the causes of failure and to determine the parameters that can be measured the actual condition. As the results of the risk assessment, a method to monitor the main bearing LO outlet temperature was selected for the main engine main bearing to which the CBM method is applied in this study.

We also evaluated the feasibility of identifying bearing damage by monitoring the main bearing LO outlet temperature. In addition, whether the damage can be properly identified using measured actual ship data was also examined. In order to verify the validity of the technique, a land-based test was conducted to simulate the installation conditions, and the feasibility of CBM application was examined.

3.1 Actual Ship Onboard Monitoring

A temperature measuring resistor was installed through the base saddle as shown in the as-installed view in Fig. 1 to collect the main bearing LO outlet temperature as continuous data on a real ship and investigate the effectiveness of the data analysis technique.

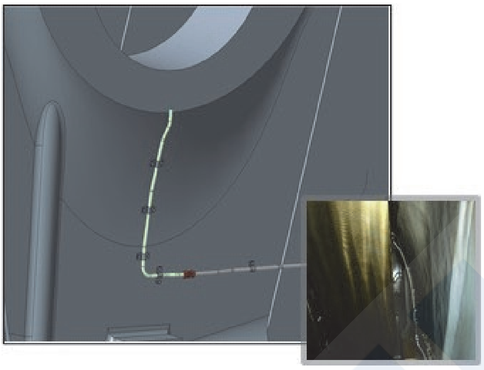

Fig. 1 View as-installed on real ship

The following Fig. 2 shows the main bearing LO outlet temperatures measured in December 2019 (vertical axis = temperature [°C]; horizontal axis = time [days]; black plot = main bearing No. 2; red plot = main bearing No. 4). In the portions enclosed in the circles, the corresponding temperatures were increased by adding +1 °C to the measured data. The possibility of instantaneous temperature rise was examined to verify the effectiveness of the analysis.

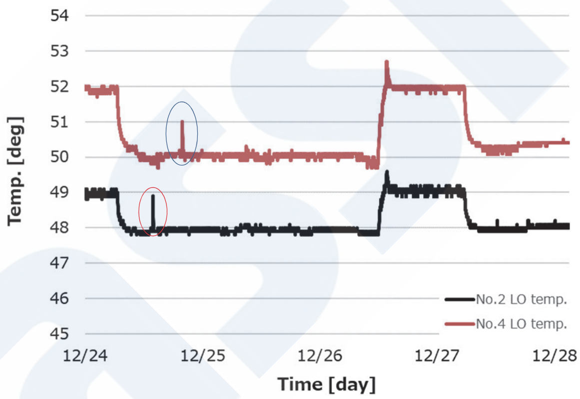

Fig. 2 LO outlet temperatures of main bearings No. 2 and No. 4 (December)

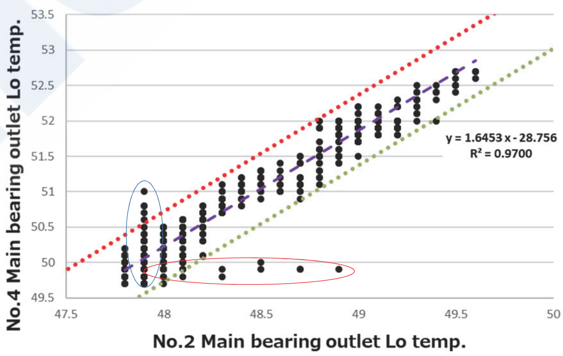

Fig. 3 Correlation plot chart for LO outlet temperatures of main bearings No. 2 and No. 4 (December)

As shown in Fig. 3, the main bearing LO outlet temperatures have an identical gradient. Therefore, when a correlation is taken between the outlet temperatures of main bearings No. 4 and No. 2, with the former and the latter on the vertical and horizontal axes, respectively, a regression line can be drawn as shown by the blue dashed line in the above figure. Most of the resultant data fall within the ± 0.5°C range defined by the parallel red and green dotted lines above and below the regression line. The plot portions encircled in red and blue in Figs. 2 and 3 show that the data for the instantaneous temperature rise in main bearing No. 2 spreads horizontally in the rightward direction, while the plot for instantaneous temperature rise in No. 4 extends vertically upward. This means that abnormal values can be judged clearly by setting a temperature range corresponding to this correlation. It is considered appropriate to check the raw measurement data in order to confirm the time of occurrence when using the analysis method presented above for anomaly determination.

Fig. 4 shows part of the measurement results obtained from main bearings No. 2 and No. 4 in June 2020 (vertical axis = temperature [°C]; horizontal axis = time [days]). The sensor for No. 4 malfunctioned, causing part of the continuous data to represent partial fluctuations.

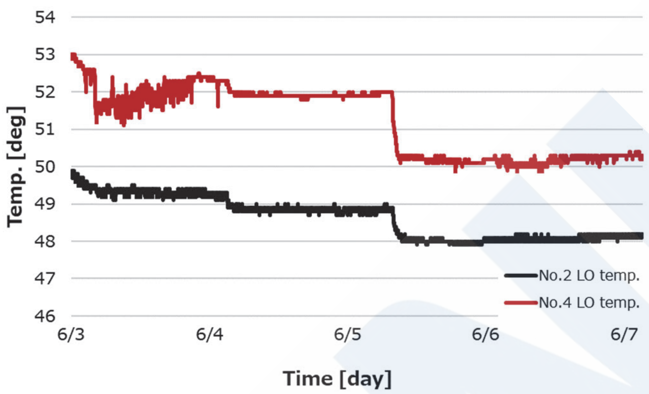

Fig. 4　LO outlet temperatures of main bearings No. 2 and No. 4 (June)

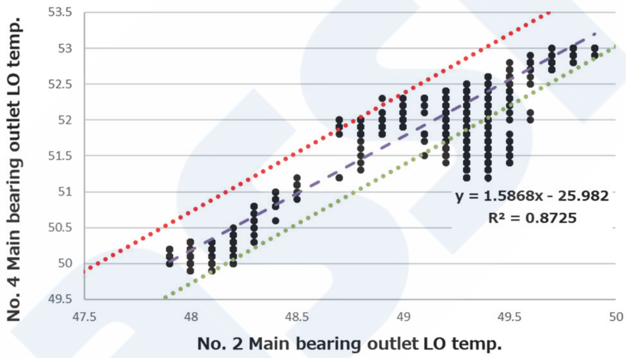

Fig. 5　Correlation plot chart for LO outlet temperatures of main bearings No. 2 and No. 4 (June)

Fig. 5 shows the results of a similar analysis for the situation in which fluctuation occurred in No. 4. Here, a cluster of data points falls outside the parallel lines representing the temperature range of ±0.5 °C. During the fluctuation phenomenon on the No. 4 bearing side, the No. 2 bearing side temperature changed slightly, causing some data to fall outside the ±0.5 °C range and spread horizontally. In this analytical approach, interpretation of the plotted data became more difficult as the number of data falling outside a set range increased. Hence, this approach is suitable for analyzing short-term measurement results and requires a concurrent raw data check.

3.2　Simulation Test

When adopting equipment condition monitoring, the effectiveness of the technology must be examined. In the present study, bearing damage modes were analyzed to investigate the effectiveness of bearing damage monitoring by bearing LO outlet temperature monitoring. Fig. 6 shows the wear modes of a slide bearing. After installation, a bearing is subjected to run-in for a better fit to the shape of the contact face. During this run-in period, the bearing becomes smoother while undergoing greater wear than during normal operation. During the subsequent normal operation, the bearing gradually wears under cyclic loads until it reaches the abnormal wear phase due to such factors as wear growth and absence of oil film, resulting in eventual burnout or breakage.

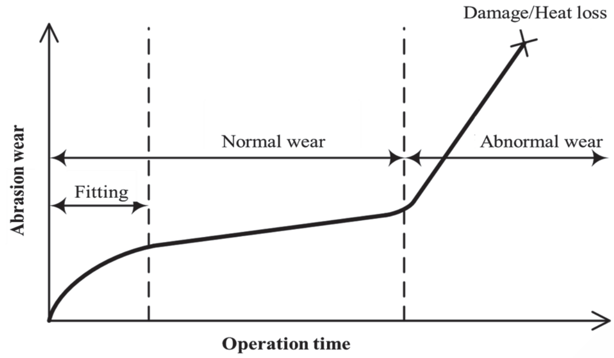

Fig. 6 Wear of slide bearing

In addition to the abnormal wear mentioned above, fatigue fracture also occurs in bearings. The main causes of fatigue fracture are excessive overall or local contact pressure on the bearing or excessive thinning of the oil film thickness, etc. In addition to the above-mentioned abnormal wear and fatigue fracture, other causes of bearing damage include corrosion due to the use of a lubricating oil with poor properties, and other forms of erosion such as cavitation and galvanic corrosion. However, since these other causes only account for a small portion of the causes of bearing damage, they are not included in the present study.

A simulation test assuming real onboard conditions was conducted to collect data on anomalies and investigate the correlation between the occurrence of anomalies and measured values. Fig. 7 shows the confirmation test results for seizure (vertical axis = temperature [°C]; horizontal axis = time [days]).

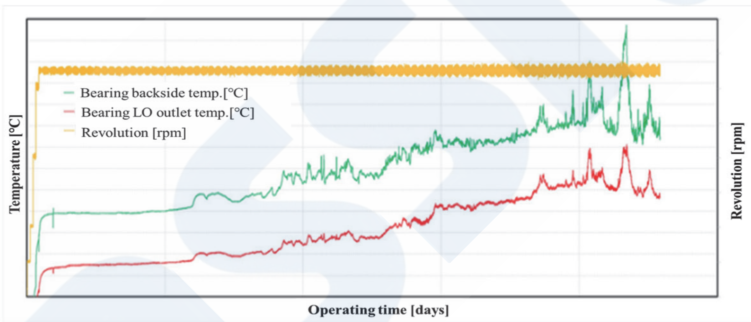

Fig. 7 Results of confirmation test for seizure

In a condition in which damage was caused intentionally by applying a high load and high rotation speed, the initial damage phase was detected by an increase in the LO outlet temperature. Subsequently, the LO outlet temperature rose at almost the same time as the bearing backside temperature increased, and after seizure occurred, more remarkable temperature changes were observed. Fig. 8 shows the appearance of the bearing surface after the completion of the test.

Fig. 8 Bearing metal surface after simulation test

A test was conducted under the same conditions to confirm the damage steps during the initial phase. After the initial-phase temperature rose, as in Fig. 9, the test was stopped and the specimen was checked.

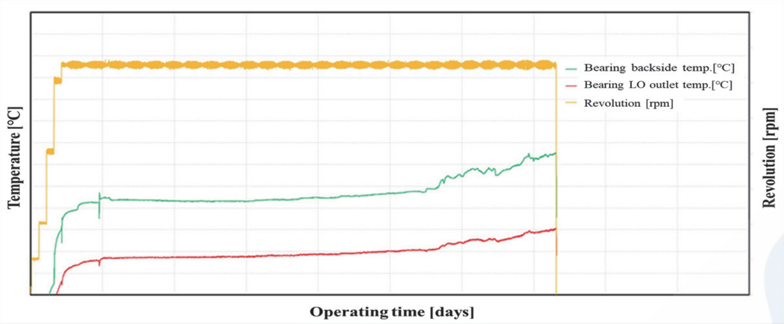

Fig. 9　Results of confirmation test for seizure

As a result, the damage shown in Fig. 10 was observed.

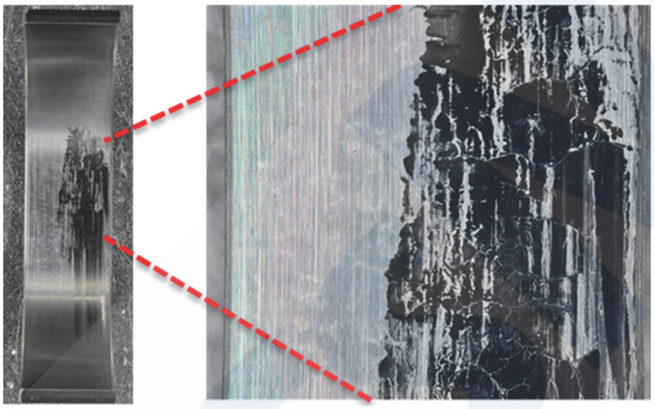

Fig. 10　Bearing metal surface after seizure confirmation test

Thus, this test demonstrated that the main bearing LO outlet temperature reflects the bearing metal temperature, as the outlet temperature gradually rose, and metal damage can be detected by monitoring the outlet temperature.

4. CONCLUSION

The purpose of this study is to contribute to the industry with new efficient and reliable methods of CBM. The current CBM is still limited, as diagnostic technologies have not yet been established for many areas, and there will be stronger needs for pass/fail judgment by condition diagnosis at the level of individual equipment parts.

ClassNK provides validation of new survey techniques to facilitate smooth survey by condition anomaly monitoring. This paper presented a study of assessment of the damage of bearing metal by monitoring the main bearing LO outlet temperature. The results of an actual ship onboard test demonstrated the effectiveness of main bearing LO outlet temperature monitoring as a more accurate anomaly determination method through proper data analysis. In addition, the results of a simulation test showed that it is possible to understand the condition of bearing damage based on initial-phase anomaly conditions by main bearing LO outlet temperature monitoring.

Thus, this study confirmed that bearing damage monitoring is feasible by measurement, monitoring and analysis of main bearing LO outlet temperature.

We will continue exploring new CBM technologies and publish the progress of those efforts in order to contribute to the maritime industry as a whole.

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