PAPER • OPEN ACCESS

Study on Wear Regulation of Diesel Engine Based on Oil Analysis

View the article online for updates and enhancements.

Study on Wear Regulation of Diesel Engine Based on Oil Analysis

Guoliang Sun*

China Satellite Maritme Tracking and Control Department, Jiangyin, China, 214431

*Corresponding author e-mail: 151684781@qq.com

Abstract: In this text, the study was conducted to the diesel engine running process by oil analysis. Based on the spectrographic analysis and ferrographic analysis, the extraction of lubricant analysis results have been completed by various methods as limits method, tendency chart method and linear regression method. On the basis of information issued from above analysis, the wearing tendency model of diesel engine has been established to assess the diesel running quality. It has been proved that the running quality of 1# main diesel engine is better than that of 2# main diesel engine.

1. Introduction

The mechanical wear of the diesel engine during operation is a problem that cannot be ignored, which directly affects whether the diesel engine can operate in the service life normally, safely, and reliably. For the oil status of diesel engine, there is no comprehensive detection means, unified evaluation standards and efficient management platform, which may result in failure of pre-judgment for possible hidden troubles of the equipment, and maintenance support work still remains at the " maintenance upon-failure" stage.

In view of the equipment wear in the operation of marine diesel engine, the oil analysis method was used to collect the diesel engine lubricating oil sample and related information during a certain operation period, and the lubricating oil sample was subject to spectrographic analysis and ferrographic analysis, and the characteristic information was extracted from the data obtained from the analysis. With the combination of the ferrographic characteristic images and the characteristic information in the performance parameters of diesel engine, plus other relevant thermal parameter information, the boundary value analysis method and the trend graph analysis method were used to comprehensively analyze the lubrication wear trend of the diesel engine, which is of great significance for daily maintenance of diesel engines and repair work in ships [1].

The basic research roadmap of this paper is shown in Figure 1. The lubricating oil sample in the diesel engine was extracted according to a fixed cycle, and the composition, concentration and shape of the abrasive grains in the lubricating oil were tested and analyzed, and the operating state of the equipment was judged. The research contents mainly involved three aspects: research on the diesel engine wear mechanism; oil wear monitoring analysis method and prediction of wear trend.
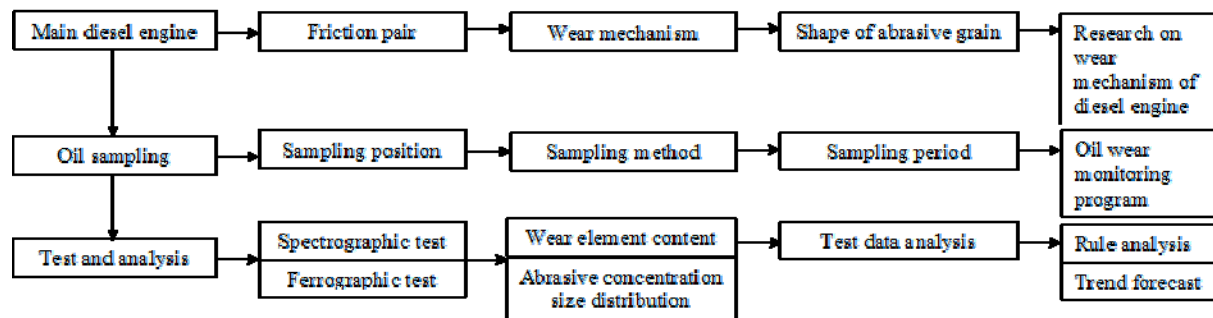
Figure 1 Research Roadmap of this Paper

2.   Analysis of diesel engine oil system

As the core device of the power plant, the diesel engine is the "heart" of a ship, and its performance is very important. The oil system is its main subsidiary system, used for delivering a sufficient amount of oil to the diesel engine to meet its quality requirements. Therefore, the quality of the lubricating oil shall be guaranteed to meet the requirements for use. Its main functions are:

(1) Wear reduction, (2) Cooling, (3) Cleaning, (4) Sealing, (5) Noise reduction, (6) Transmission, and (7) Corrosion protection.

The measuring ship diesel engine adopts a dry-sump lubricating system, and the lubricating oil of the diesel oil lubricating system is stored in a separate lubricating oil circulating tank (with steam heating line) outside the engine body, and the sump is only used to collect the lubricating oil flowing down from various lubrication parts. As shown in Figure 2, it mainly consists of lubricating oil circulating tank, oil pre-supply pump, oil standby pump, oil cooler, oil automatic backwashing filter, oil double indicating filter, oil conveying line and control valve.
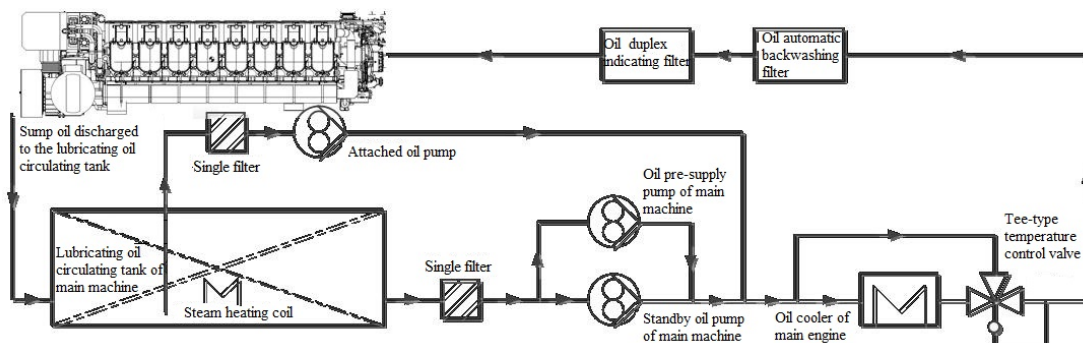

Figure 2 Dry-sump Lubricating System

The lubricating oil circulating tank is set under the main machine, and the main machine's oil is taken from the lubricating oil circulating tank, pumped out by the front-end pre-supply pump, or by the rear-end attached oil pump, and cooled by the oil cooler. In order to ensure the temperature of the incoming oil meets the use requirement, part of the oil flows through the oil cooler, and the other part of the oil bypasses. The electric tee-type temperature control valve can control the temperature of oil entering the main machine by adjusting the amount of oil entering the oil cooler.: If the temperature of the oil entering the main engine is low, the flow of the lubricating oil into the lubricating oil cooler is reduced; if the temperature of the lubricating oil entering the main machine is high, the flow of the lubricating oil into the lubricating oil cooler is increased.

3.   Sampling Scheme

3.1. Sampling Position

No matter in what kind of system, not the oil sample taken from any part can represent the true friction, wear, lubrication and contamination of the system. For the circulation system, sampling should be

done before the oil return filter of the oil returning line of the equipment, and the positions are usually selected as the oil return line of the oil, the pressure line before the oil pump outlet filter, the oil sump, the circulating oil tank, etc. When sampling on the return line, try to avoid sampling from the bottom of the line, and before sampling, a part of the oil should be drained first to clean the drain valve and ensure the dynamic and regular oil sample is taken.

The most common sampling position is one point on the oil return line before the friction pair in the equipment's lubrication system, or a fixed point in the lubricating oil tank. Such position should truly reflect the state and characteristics of the system. The sampling point for this paper is in the oil return line of the oil separator for the diesel engine's lubricating system.

3.2. Sampling Conditions

According to the test requirements, the oil sample taken should fully contain the wear grains and pollutants in the lubricating oil. This requires that the various grains in the lubricating system are fully suspended during sampling. Therefore, sampling should be preferably done when the system is working.

3.3. Sampling Method and Apparatus

The sampling bottle is made of high-density chemical reaction -resistant white polyethylene, with a capacity of about 250 ml, and about 500 ml for physical and chemical analysis. The oil sample bottle shall have a permanent sampling mark, which indicates the position to be reached by the on-site sampling liquid level to ensure that the sample bottle still retains a certain volume space after a sufficient amount of oil sample is taken, so that the oil sample is heated and shaked to be even before analysis.

3.4. Sampling Period and Record

It is especially important to determine a reasonable sampling period. If the sampling interval is too short, it will inevitably increase the cost and unnecessary analysis. If the sampling interval is too long, some important fault information may be missed. The sampling period shall be determined with comprehensive consideration of various factors such as the machine's degree of importance,service life, operating procedures and load characteristics, safety issues, urgency from the beginning of the abnormality to the failure. Experience has shown that different machines, different operating periods, and different wear conditions should have different optimum sampling intervals. The sampling period of the oil sample in this paper is 200h.

4. Data Analysis

Since August 2015, the regular oil sampling has been carried out within 4000 hours after the oil replacement of two diesel engines of a certain ship, and the sampling is dynamic. The sampling position is on the oil return line before the oil separator filter. The sampling interval is 200h. 20 oil samples were obtained for each. The oil sample numbers are shown in Tables 1 and 2. The oil samples were subject to oil spectroscopy and iron spectroscopy, and the test data were obtained.

Table 1 Oil Sample Numbers for 1# Main Diesel Engine

No.	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10
Operation time after oil replacement /h	195	386	589	796	1005	1187	1378	1598	1790	2005
No.	1-11	1-12	1-13	1-14	1-15	1-16	1-17	1-18	1-19	1-20
Operation time after oil replacement /h	2180	2393	2615	2809	2999	3187	3405	3590	3804	3997

Table 2 Oil Sample Numbers for 2# Main Diesel Engine

No.	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10
Operation time after oil replacement /h	191	390	597	805	1998	1203	1410	1597	1788	1998
No.	2-11	2-12	2-13	2-14	2-15	2-16	2-17	2-18	2-19	2-20
Operation time after oil replacement /h	2190	2401	2589	2797	3004	3200	3399	3585	3798	3995

4.1. Trend Graph Analysis

(1) 1# Diesel Engine   (2) 2# Diesel Engine
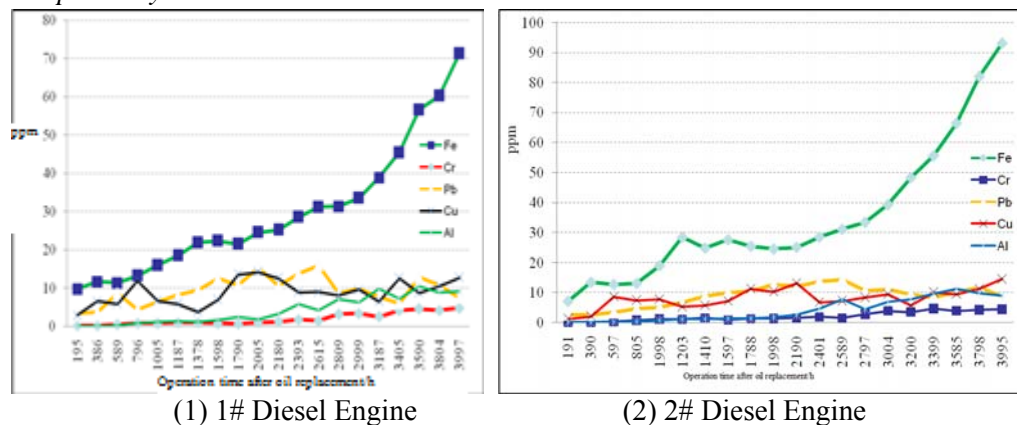
Figure 3 Analysis of trends in the content of different elements

The contents of main elements in the spectrum analysis of 1# diesel engine after oil replacement were different, the content of iron continued to increase, and the increase amplitude was large; the contents of lead and copper changed more slowly; and the contents of aluminum and chromium increased slowly. The iron element mainly came from the friction pair such as cylinder liner and piston; the chromium element was mainly from the piston ring; the aluminum element was mainly from the piston; and the copper and lead were mainly from the main bearing and the bearing bush friction pair. The contents and change trends of the main elements of 2# diesel engine were similar to those of 1# main diesel engine. The content of iron element was gradually increased, but the concentration trends of chromium, lead, copper and aluminum were basically the same, and the range of variation was not large, based on which, it may be judged that the friction pair such as the cylinder liner and piston ring has a certain degree of wear, but the piston and the bearing bush friction pair were not worn much, and all within the normal range.

In order to better understand the working process of the diesel engine friction pair and mutual-influencing factors, the correlation of the wear elements of the 1# diesel engine was analyzed [2].

1) Correlation between aluminum and iron
The content of aluminum increased with the increase of iron content, and the change trend is shown in Figure 4, which indicates that the piston wear of the diesel engine was aggravated with the increase of the wear gap of the liner.
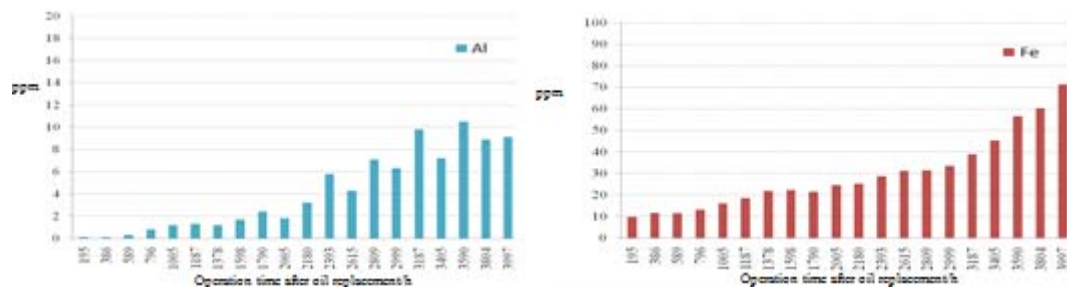
Figure 4 Change trend of aluminum and iron contents

2) Correlation between aluminum and chromium

The content of aluminum increased with the increase of chromium content, and the change trend is shown in Figure 5, which indicates that the wear of the piston ring of the diesel enginewas aggravated with the wear of the piston. The correlation analysis of aluminum content as well as iron and chromium content indicates that the piston of the diesel engine was sharply worn with the wear of the cylinder liner-piston ring.
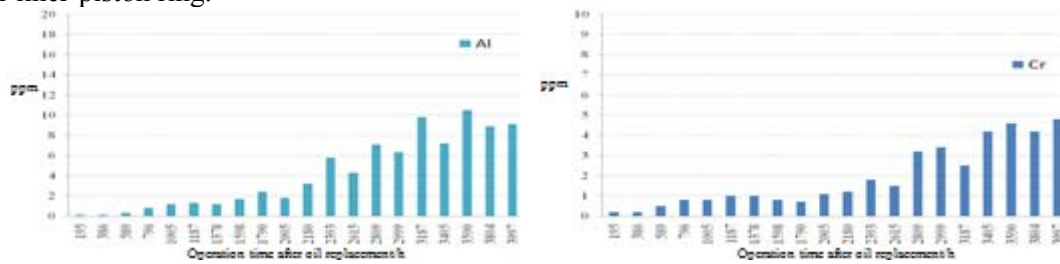

Figure 5 Change trend of aluminum and chromium contents

3) Correlation between chromium and iron

From the trend that the content of chromium element changed with the content of iron element (as shown in Fig. 6), the trend of the simultaneous increase of chromium content and iron element is quite obvious. This indicates that the correlation between chromium and iron is also very strong. The chromium concentration exceeding the standard, is necessarily accompanied by the iron concentration exceeding the standard. Therefore, the chromium concentration is a characteristic indicator reflecting the wear of cylinder liner-piston ring.
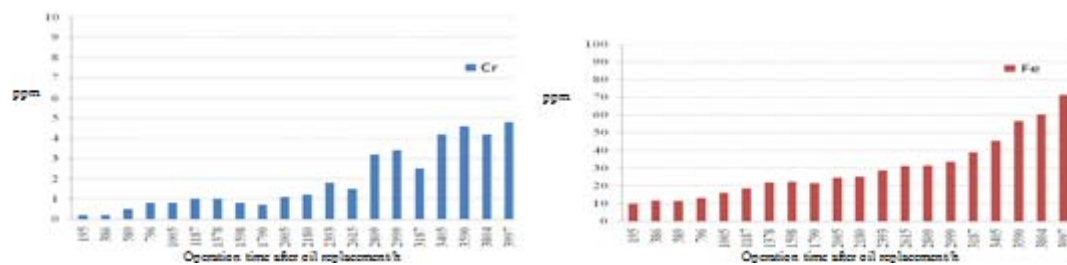

Figure 6 Change trend of chromium and iron contents

4) Correlation between copper and iron

It can be seen from Figure 7 that the trend of simultaneous increase of copper and iron is not significant. This indicates that in most cases the iron content is mainly generated from the wear of cylinder liner. The copper element is mainly from the wear of the main bearing. Under normal circumstances, the copper content is low and the increase is relatively slow. When the main bearing friction pair is seriously worn, a large amount of copper and iron abrasive grains will be generated. Therefore, from the trend graph showing the change of copper content with the iron content, the following conclusions can be drawn: First, the increase of iron content is not necessarily accompanied

by the increase of copper content; second, the increase of copper content is necessarily accompanied by the increase of iron content.

Figure 7 Change trend in copper and iron contents

4.2. Boundary Value Analysis Method

It is found from research that the concentration distribution of abrasive grains in the process of mechanical wear basically conforms to the Gaussian normal distribution. Under this assumption, the three-line value method is generated [3]. The three-line value method is a method for calculating the absolute value of monitoring data, describing the overall trend of the equipment system with time as the main line. It is a longitudinal analysis method that aims to create the wear trend graphs including calculated parameter time curves, baselines, warning lines, and hazard lines to visually reflect the wear state of the equipment. In the calculation, the 3σ method is generally used, and the normal boundary value is set as $\mu+\sigma$, the warning boundary value is $\mu+2\sigma$, and the dangerous boundary value is $\mu+3\sigma$, where μ is the average value of all the measured samples, and σ is the standard deviation [4]. Table 3 through Table 6 show the calculation results of the spectrographic and ferrographic boundary values.

Table 3 Spectrographic analysis boundary values for 1# diesel engine wear elements

Metal element	Fe	Cr	Pb	Cu	Al
Average μ	30	1.9	9.3	8.9	4.2
Standard deviation σ	17.2	1.6	3.6	3.3	3.6
Normal value $\mu+\sigma$	47.2	3.5	12.9	12.2	7.8
Warning value $\mu+2\sigma$	64.4	5.1	16.5	15.5	11.4
Dangerous value $\mu+3\sigma$	81.6	6.7	20.1	18.8	15

Table 4 Spectrographic analysis boundary values for 2# diesel engine wear elements

Metal element	Fe	Cr	Pb	Cu	Al
Average μ	35	2	9	8.2	4.1
Standard deviation σ	23.2	1.5	3.6	3.3	3.8
Normal value $\mu+\sigma$	58.2	3.5	12.6	11.5	7.9
Warning value $\mu+2\sigma$	81.4	5	16.2	14.8	11.7
Dangerous value $\mu+3\sigma$	104.6	6.5	19.8	18.1	15.5

Table 5 Ferrographic parameter boundary values for 1# diesel engine

Metal element	D_L	D_S
Average μ	6.86	4.12
Standard deviation σ	1.76	1.31
Normal value $\mu+\sigma$	8.62	5.43
Warning value $\mu+2\sigma$	10.38	6.74
Dangerous value $\mu+3\sigma$	12.14	8.05

Table 6 Ferrographic parameter boundary values for 2# diesel engine

| Metal element	D_L	D_S
Average μ	7.21	3.69
Standard deviation σ	1.58	0.80
Normal value μ+σ	8.79	4.49
Warning value μ+2σ	10.37	5.29
Dangerous value μ+3σ	11.95	6.09

4.3. Linear Regression Analysis

A basic requirement for diesel engine condition monitoring and fault diagnosis is to predict the operating trend for a certain period of time thereafter. The trend analysis method is based on statistics. First, the three-line value map of the spectrum analysis or the ferrographic analysis is drawn with the statistical method, and the spectrum or the ferrographic data of the diesel engine for continuous times of tests are marked in the three-line value map. The linear regression method is used to fit them into a straight line. The time corresponding to the intersections between this line and the normal value, the warning value and the dangerous value lines can be used to indicate the period of time during which the diesel has been in a certain wear state, and any time can be given, to obtain   the predicted values, achieving the purpose of prediction[5].

In order to evaluate the comprehensive wear trend of diesel engines, this paper selected D_L, an index of large grain reading in the ferrographic analysis data for analysis. Firstly, the linear regression equation (y=ax+b)of the large grain reading was calculated,and then the three-line value map of the large grain reading was drawn. According to the intersections of the regression equation with the normal value line, the warning value line, and the dangerous value line, the corresponding time (t1, t2, t3)was obtained. The analysis process is shown in Figure 8.
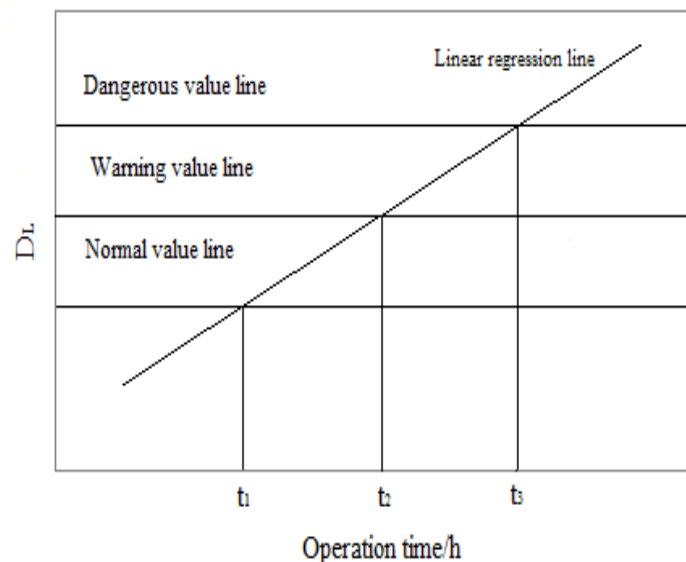
Figure 8 Diesel engine wear trend prediction chart

The linear regression equations of the large grain spectrum reading of the ferrography of 1# and 2# main diesel engines are shown in Fig. 9. The calculated values of durations for different wear states of the diesel engine are shown in Table 7.
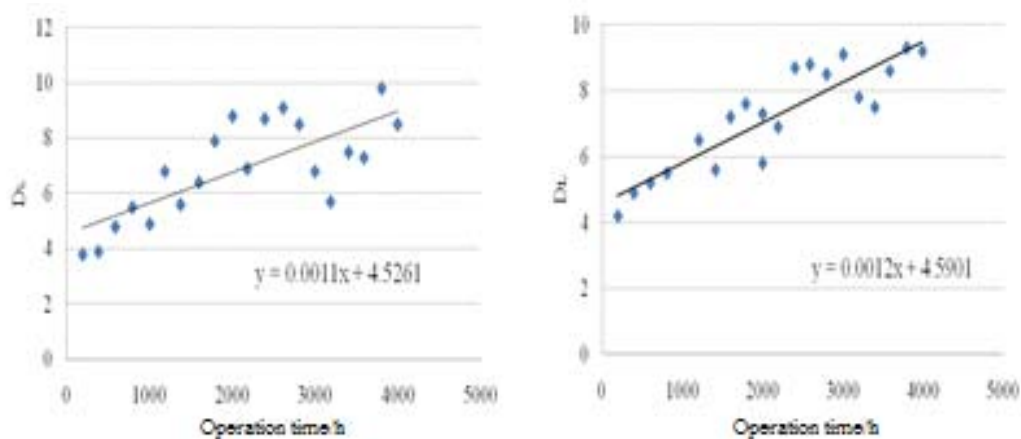
(a) 1# diesel engine (b) 2# diesel engine

Fig. 9 Linear regression equation of large diesel particle readings of two diesel engines

Table 7 Duration values for different wear states of diesel engine

Time（h）	t_1	t_2	t_3
1# main diesel engine	3721	5321	6922
2# main diesel engine	3500	4817	6133

When the diesel engine's running time $t < t_1$, the wear state is in the normal area, the diesel engine can work safely and reliably; when $t_1 < t < t_2$, it is a precursor to abnormal wear, necessary attention is required, and the monitoring on the diesel engine should be strengthened, so that any problem is timely solved once it is found; when $t_2 < t < t_3$, the wear state is in the warning area. At this time, the wear of the diesel engine is in an abnormal state. It needs a process from abnormal wear to failure, in such process, the number of large abrasive grains will increase rapidly. Although abnormal wear occurs, it will not immediately fail. When $t > t_3$, the wear state is in the dangerous area, the wear rate increases rapidly, and the diesel engine will be subject to failure.

It can be seen from Table 6 that the t_1, t_2, and t_3 values of 1# main diesel engine are all larger than that of 2# main diesel engine, which indicates that 1# main diesel engine in the actual operating state is superior to 2# main diesel engine, which is basically consistent with the result of spectrographic analysis and ferrographic analysis. Due to the influence of external and internal uncertain factors in the operation of the diesel engine, the operation rule of the diesel engine was fluctuated and the monitoring data was limited, so these time boundary values can be used as a basic estimate for the prediction of the diesel engine wear trend, but a large amount of experimental data is still required for in-depth study.

5. Conclusion

Based on the research in this paper, the following methods can be used to monitor the wear during the operation of the diesel engine:

① Use the oil spectrum and ferrographic analysis data to calculate the boundary values of main wear element contents and direct reading ferrographic data, and use them as the monitoring standards;

② After analyzing the collected oil sample, it can be judged whether the running state of the diesel engine is normal by the boundary value judgment;

③ Further determine where the abnormal wear occurs, with the combination of the correlation analysis of wear elements, if abnormal wear occurs.

Since the diesel engine is affected by external and internal uncertain factors during operation, the limits of diesel engine spectrographic analysis and ferrographic analysis are dynamically changed. In

daily work, oil samples should be collected periodically to accumulate the analytical data so that appropriate equipment maintenance measures may be taken in a timely manner according to the change of operating conditions.

References

[1] Shi Hong, Zhang Shuai and Li Ang. Prediction of oil metal content based on structural optimization RBF neural network[J]. Lubrication and Sealing 2012, 37(11): 35-38.
[2] Yu Shude, Xu Shiyong and Liu Xinhua. Pretreatment of spectrographic data in the diagnosis of diesel engine oil [J]. Lubrication and Sealing, 2011, 36(8): 105-108
[3] Li Jin and Chen Guoshou. Introduction to the application of ferrographic analysis in lubrication monitoring[J]. Synthetic Lubricant, 2013, 40(2): 39-41.
[4] Liu Yubin, Li Zhuguo and Yang Zhiyi. Study on the deposition rule of wear debris on the spectrum by rotary ferrograph[J]. Lubrication and Sealing, 2003(4): 39-42.
[5] Zhang Shuai, Li Ang, Shi Hong and Li Nan. Aeroengine wear trend prediction based on grey neural network combination model[J]. Journal of Shenyang Aerospace University, 2012, 29(3): 84-88.