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Research on Monitoring Method of Gear Wear Status Based on Characteristics of Abrasive Particles

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Abstract. Aiming at the problem that it is difficult to extract the characteristics of the spectroscopy group and the characteristics of the granules cannot be fully judged, based on the gear wear test, this paper proposes to extract the multi-feature parameters of the abrasive grain group and comprehensively analyze the gear wear state. Firstly, the obtained abrasive grain image is pretreated to remove the influence of the shadow area on the characteristics of the extracted abrasive grain group. Then, the abrasive grain coverage area index (IPCA), the abrasive grain length, the abrasive grain width and the abrasive grain area distribution are extracted. Finally, the characteristic parameter data values are obtained and the trend graph is drawn to determine the state of the different wear stages of the gears, this method is suitable for condition monitoring under gear wear conditions.

1. Introduction

As a direct product of the friction pair, abrasive particles are important information for analysing and judging the failure of mechanical equipment. The characteristics of the concentration, shape and size of the abrasive grains generated by the gears under continuous operation will change and the individual characteristics of the abrasive grains will be different. The single abrasive grain characteristics cannot fully and accurately reflect the wear state. The complexity and diversity characteristics of the abrasive grain group of a large number of abrasive grains can better explain the actual working conditions of the wear. Therefore, the equipment wear is effectively monitored by extracting the characteristic parameters of the abrasive grain group. The state is of great concern to researchers.

The current single abrasive grain characteristics (size, texture, area, perimeter, color, etc.) are widely used in off-line ferrography analysis and the technology is relatively mature. Due to the complexity of the abrasive grain group itself, there are few studies on the characteristics of the abrasive grain group. Secondly, Due to the limitations of offline metallographic analysis and the strict requirements of the sampling process, it is unable to meet the real-time monitoring requirements of mechanical equipment. Again, the online ferrography acquires low image resolution, due to the influence of illumination factors, in the light of a single ferrographic image. The intensity is different, and the background area produces shadows, resulting in poor background subtraction.



Based on the above factors, this experiment uses the online ferrography sensor to obtain the wear and tear information of the gear wear; the segmentation method of the colored ferrography image is proposed to realize the abrasive grain segmentation; combined with the comprehensive and accurate advantages of multi-parameter analysis, the segmentation of the abrasive grain is marked by image marking method. The length of the abrasive grains, the width of the abrasive grains and the area distribution of the abrasive grains were taken as the characteristic parameters of the abrasive grain group. The data values of the characteristic parameters of the abrasive image group of the iron spectrum image were calculated, and the histogram of the frequency and size characteristics of the abrasive particles was drawn, and the parameters were integrated. The comparison shows the state of the gear wear phase.

2. Abrasive online monitoring system

The on-line monitoring system for abrasive particles is an online visual iron spectrum (OLVF) characterized by direct reading and online analysis. Figure 1 shows the schematic diagram of on-line monitoring of gear wear abrasive particles. The abrasive particles generated by gear wear accompany the lubricating oil into the oil passage, deposit ferromagnetic particles in the lubricating oil under the action of electromagnetic field, and obtain the deposited abrasive grain iron spectrum by CMOS sensor. The image is stored by computer software to obtain the abrasive information acquisition during the gear operation.

The main features of the gear wear monitoring system are: (1) the amount of oil entering the oil passage of the gear oil and the variability of the magnetic quantity of the electromagnet; (2) the acquisition of the ferrographic image of the real-time full-life of the gear wear; (3) Unattended, complete automatic sampling analysis.

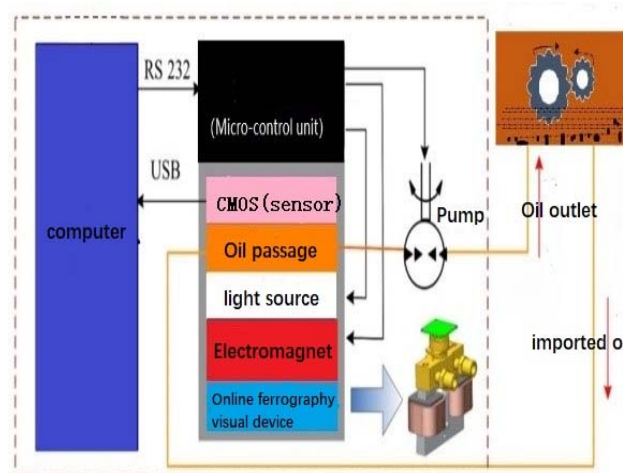


Figure. 1 Abrasive monitoring schematic

3. Identification of on-line ferrography image abrasive grain groups

The iron spectrum image obtained by gear wear online is stored as a color image with a unit length of. Due to the light projection factor, the acquired color ferrography image is divided into two areas of “bright band” and “black band”, and the bright band area needs to be image processed to segment the desired abrasive grains.

The middle area of the online color spectrum image is bright, the sides are relatively dark, the background color of the image is not uniform, and some black shadows appear between the bright band and the black band area. As shown in Fig. 3, the general grayscale threshold segmentation method is easy to divide the black shading of the regions on both sides of the bright strip into abrasive grains, resulting in inaccurate segmentation of the abrasive grains. To solve this problem, this paper

adopts the background subtraction method of the iron spectrum image based on the color component ratio.

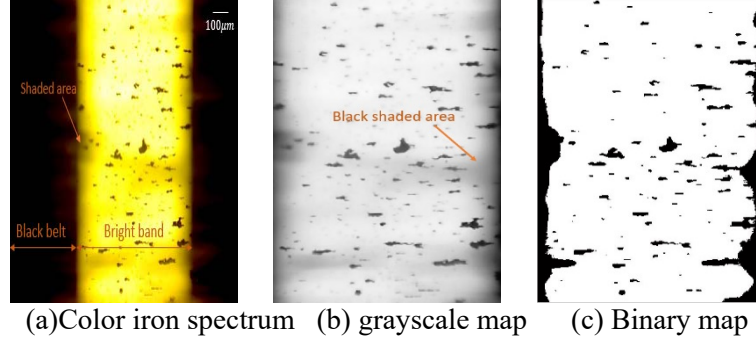


Figure. 2 Abrasive image segmentation

Although the background color of the iron spectrum image is different in brightness and brightness, the ratio of the color component of the background part is stable under different light, and the ratio of the color component of the background to the worn abrasive grain is larger, and the color component is subtracted from the background. Threshold segmentation method. Let the total number of pixels of the original image be N , and the three color components of each pixel point are represented by r_i, g_i, b_i ($i = 1, 2, 3 \dots N$), first calculate the average value of the ratio of the three color components of the image:

$$\text{Red and green color component ratio (r/g) average: } q_1 = \frac{1}{N} \sum_{i=1}^N \frac{r_i}{g_i} \quad (1)$$

$$\text{Red and blue color component ratio (r/b) average: } q_2 = \frac{1}{N} \sum_{i=1}^N \frac{r_i}{b_i} \quad (2)$$

$$\text{Green and blue color component ratio (g/b) average: } q_3 = \frac{1}{N} \sum_{i=1}^N \frac{g_i}{b_i} \quad (3)$$

Second, calculate the standard deviation of the ratio of the three color components:
The red and green color components are worse than the standard deviation:

$$\sigma_1 = \sqrt{\frac{\sum_{i=1}^N \left(\frac{r_i}{g_i} - q_1 \right)^2}{N-1}} \quad (4)$$

The red and blue color components are worse than the standard deviation:

$$\sigma_2 = \sqrt{\frac{\sum_{i=1}^N \left(\frac{r_i}{b_i} - q_2 \right)^2}{N-1}} \quad (5)$$

The green and blue color components are worse than the standard:

$$\sigma_3 = \sqrt{\frac{\sum_{i=1}^N (\frac{g_i}{b_i} - q_3)^2}{N-1}} \quad (6)$$

The background subtraction is performed by selecting the ratio of the two color components of the three color components that are larger than the standard deviation difference, and the error range of the color component ratio is determined:

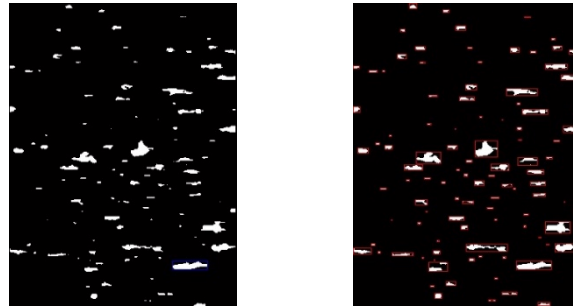
$$\begin{cases} q_{i\min} = q_i - a \\ q_{i\max} = q_i + a \end{cases} \quad i = 1, 2, 3 \quad (7)$$

The background color of the picture determines the value range. According to the image obtained by the experiment, the ratio of the color components of red, green and blue is used. The value ranges from 0.2 to 0.8. The background is subtracted according to the error range of the average value of the color component ratios and the ratio of the color component ratios. The basis for judging the background is: for each pixel, if the component ratio is within the error range, it is the background.

Let $f(x, y)$ be the original abrasive grain image, the three color components are $f_r(x, y)$, $f_g(x, y)$, $f_b(x, y)$, and $l(x, y)$ are the results after processing the background.

$$l(x, y) = \begin{cases} 255 & f_r(x, y) / f_g(x, y) \in [q_{1\min}, q_{1\max}] \\ & \text{and } f_g(x, y) / f_b(x, y) \in [q_{3\min}, q_{3\max}] \\ f(x, y) & f_r(x, y) / f_g(x, y) \notin [q_{1\min}, q_{1\max}] \\ \text{or } f_g(x, y) / f_b(x, y) \notin [q_{3\min}, q_{3\max}] \end{cases} \quad (8)$$

The background is set to white, the color of the abrasive particles is retained, and the background of the color component ratio is used. As shown in Figure 4, the method effectively removes black shading and accurately segments the worn abrasive particles.



(c) Image after background subtraction (d) abrasive grain mark

Figure. 3 image segmentation

4. abrasive particle characteristics parameters

4.1. Abrasive length and width

The shape of the abrasive grains produced by the friction pair is irregular. In the two-dimensional morphological parameters of the abrasive grains, the parameters reflecting the geometrical dimensions

of the abrasive grains are mainly length and width. In this paper, the equivalent form of the minimum error is used to calculate the abrasive grains. Length and width. As shown in Fig. 5, the abrasive grains are marked by image marking, and two characteristic parameters of the abrasive grain length (A) and width (B) are extracted by approximating the shape of the rectangle and the ellipse.

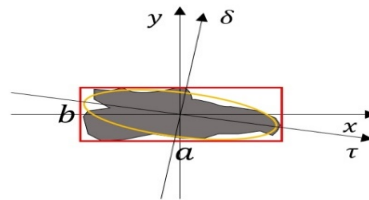


Figure .4 Equivalent abrasive grain

4.2. Abrasive area distribution

The abrasive grain area distribution is taken as a general characteristic parameter describing the abrasive grain group. Let the single-plate ferrography image have the number of abrasive grains N and the i -th abrasive grain area as S_i . Calculate the area of the abrasive grains marked in the single-spectrum image, and count the number of abrasive grains n in the corresponding abrasive grain area. Area distribution rate: $p = n/N$.

As shown in Fig. 4(d), a single ferrographic image of the wear stage is extracted, and the abrasive grains are marked to calculate the length, width and area of each abrasive grain in a single ferrographic image, as shown in Fig. 7 for the length and width of the abrasive grains. The number of abrasive particles distributed under the corresponding range of the three parameters of the area, the number of large, medium and small abrasive grains is clearly contrasted.

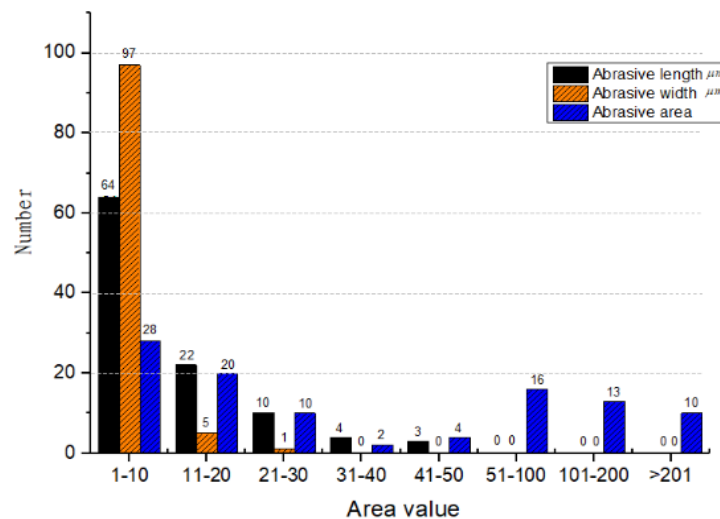


Figure. 5 Single-plate ferrography picture abrasive grain distribution map

5. verification and analysis

To verify the validity of the above three types of abrasive grain characteristic parameters. The iron spectrum image of gear wear was obtained online. The data values of the extracted characteristic parameters were calculated by MATLAB software. The whole life process of gear wear was analyzed by the extracted characteristic parameters. The feasibility of gear wear monitoring based on the characteristics of abrasive grain group was explored. Figure 7 shows four typical online ferrographic

images of the sampling gear during the wear-in period, stable wear period, severe wear period, and different wear stages of the failure period.

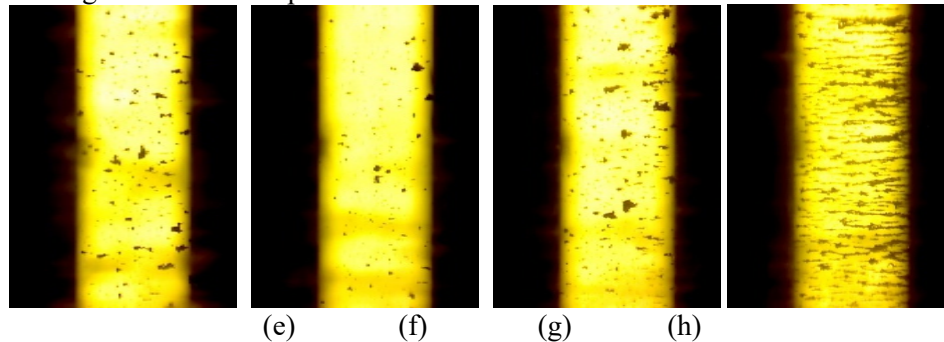


Figure. 6 Ferrograph image of different wear stages of gears

The characteristic parameters of the worn abrasive grain group are extracted. First, the background and abrasive particles are effectively separated by color background subtraction and adaptive threshold segmentation. Then, all the abrasive grains are marked to calculate the equivalent length, width, and area of each of the abrasive grain images.

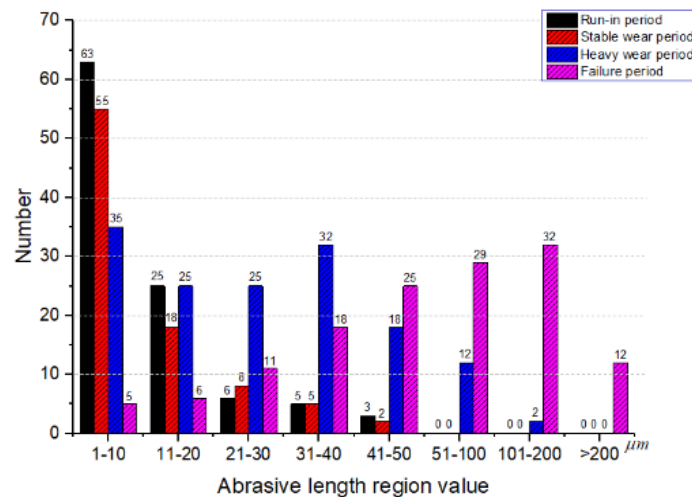


Figure .7 Wear grain length trend chart

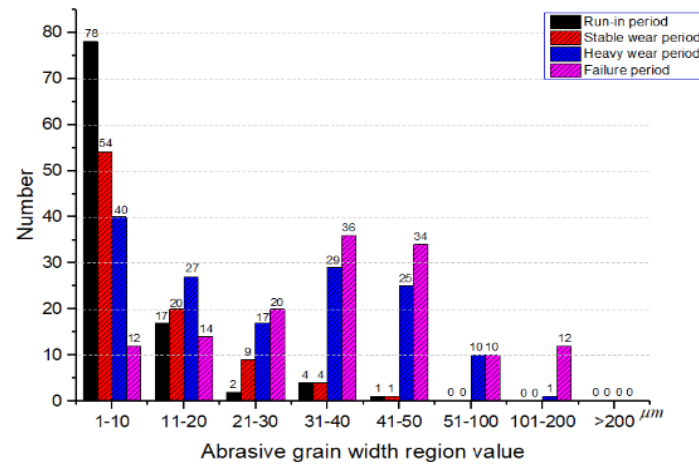


Figure. 8 Abrasive width trend chart

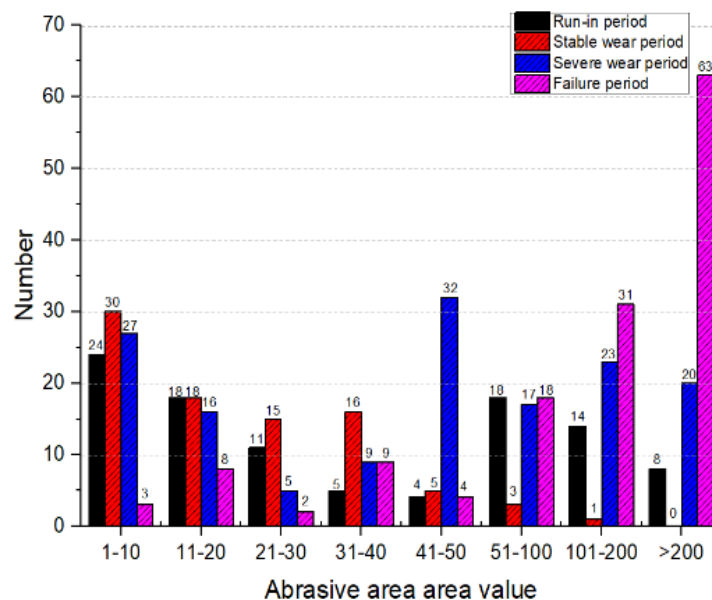


Figure. 9 Wear particle area distribution trend chart

Figures 7, 8, and 9 show the distribution of the number of abrasive grain groups of the three characteristic parameters in four different wear periods. In the initial stage of wear, the length and width of the abrasive grains are small, the number of abrasive grains less than $30\mu\text{m}$ is higher than the total proportion, and there are individual large abrasive grains; in the middle of wear, the total amount of abrasive grains is less, mainly small and medium abrasive grains; In the period of severe wear and gear failure, the abrasive grains increase sharply. From the blue histogram, it can be concluded that the length and width of the abrasive grains are larger than $50\mu\text{m}$, and the maximum size exceeds $200\mu\text{m}$. In the later stage of severe wear, the proportion of more than $50\mu\text{m}$ is more than 80%.

The occurrence of a single large wear debris during the on-line condition monitoring of gear wear is only a necessary condition for wear abnormality. Only when the number of large wear debris reaches a certain proportion, sufficient conditions for severe wear and failure are formed. The histogram can clearly and intuitively reflect the size distribution of the abrasive grain group, and

further demonstrate that the three characteristic parameters can be used to characterize the severity of gear wear.

6. Conclusion

Aiming at the problem that the off-line iron spectrum analysis period is long and the wear state of single abrasive grain characteristics is one-sided and insufficient, this paper proposes a method for online monitoring of gear wear state of multi-feature parameters of abrasive grain group. Through image processing and experimental analysis and verification, the following conclusions are drawn:

(1) Based on the color component ratio background subtraction method, the shadow area of the image can be removed, the original abrasive grain shape is well preserved, and the abrasive grain segmentation is effectively realized.

(2) The three characteristic parameters of abrasive grain length, abrasive grain width and abrasive grain area distribution are independent and complementary to each other. The data can be used to clearly and intuitively analyze the wear condition.

(3) Compared with a single abrasive grain, the group abrasive grain characteristics can fully reflect the gear wear condition.

References

- [1] Li Guobin, Guan Delin, Yu Gongzhi. Feature extraction of abrasive grain group based on singular entropy [J]. Journal of Dalian Maritime University, 2007, 33(2): 97-100.
- [2] Wu H, Wu T, Peng Y, et al. Watershed-Based Morphological Separation of Wear Debris Chains for On-Line Ferrograph Analysis [J]. TRIBOLOGY LETTERS.
- [3] Yao Zhigang. A fast method for extracting statistical features of abrasive grain groups in iron spectrum images [J]. Lubrication & Sealing, 2013(7):84-87.
- [4] Liang Man, Sun Yi, Shan Jihong, et al. Experimental study on influencing factors of particle size characteristics of flutter ball mill [J]. Chinese Journal of Mechanical Engineering, 2018, 54(7):205-215.
- [5] Li Yan. Fractal chaotic characteristics and correlation of friction signals and wear abrasive grains [D]. 2015.
- [6] Wu T H, Mao J H, Wang J T, et al. A New On-Line Visual Ferrograph [J]. Tribology Transactions, 2009, 52(5):623-631.
- [7] Lü Xiaojun, Wu Wei, Jing Mingqing, et al. A new type of online iron spectrometer [J]. Lubrication & Sealing, 2002(3):72-75.
- [8] Research on analysis method of debris characteristics of reciprocating friction pair status monitoring [D]. 2004.
- [9] Wu Huling. Study on on-line monitoring method of wear state of mine reducer based on abrasive grain characteristics [J]. Journal of Mechanical Transmission, 2017(2):177-180.
- [10] Wang Jingqiu, Wang Xiaolei. Automatic segmentation of color ferrography images based on background subtraction [J]. Lubrication & Sealing, 2011, 36(5):48-52.
- [11] Wu Tonghai, Xu Hua, Dong Guangneng, et al. Visual on-line ferrography monitoring technology for sliding bearing wear images [C]//National Tribology Conference 2007.
- [12] Wang Ruikai. Distribution of abrasive particles in online iron spectrometer [D]. Nanjing University of Aeronautics and Astronautics, 2012.