Fault Characteristics Analysis of Planetary Gear of Helicopter Main Reducer

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***Abstract*—According to the characteristics of the large transmission ratio of the helicopter main reducer in the future, the research on the characteristic distribution of the planetary gear train of the helicopter main reducer is carried out. Because of the characteristics that the heavy load condition in helicopter main reducer's running and the changeable running state and complex and harsh climatic conditions and the increasing heat of the flow field in the reducer, by the way, the large transmission ratio increases the uncertainty of the planetary gear train operation analysis at the same time, the probability of causing a failure is greater; Especially the complex and variable structure of the helicopter which has large transmission ratio main reducer makes the analysis difficulty further. For ensuring the safety and enhancing the reliability of the helicopter, this paper make a comparative analysis of the time domain characteristics of the state signals under the multi-operating condition between the normal planetary gear and planetary gears with different degrees of failure, to explore the distribution regularity of the fault characteristics of the helicopter main reducer, so as to realize the research on fault diagnosis of helicopter large transmission ratio planetary gear.**

Keywords- planetary Gear; Fault diagnosis; Threshold; ROC

I. INTRODUCTION

Under the combined action of its complex motion characteristics and dynamic nature and variable environmental excitation, the planetary gearbox makes the vibration signal's complexity, time-varying and modulation characteristics very obvious, resulting that the previous methods using in fault diagnosis for fixed-axis gearboxes. are difficult to work[1-2]. To this end, the research on planetary gearbox fault diagnosis and prediction technology has attracted the attention of many scholars at home and abroad. Among them, the research methods are roughly divided into two categories, one is based on the physical model method, starting from the fault mechanism, mechanical analysis and mathematical model, looking for the common characteristics of the planetary transmission structure when some kind of fault occurs, and then to guide fault diagnosis[3]; the other is the data-driven method. From the test data of the planetary transmission structure (mostly vibration signals), the signal processing and pattern recognition methods are used to judge whether the system has an abnormality[4].

Jae Yoon[5] et al. obtained the angle analysis from the original vibration signal, and usig the single-piezoelectric strain sensors to collect the vibration signal has the advantages

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of wide frequency range, small temperature influence, good linear range and high frequency noise interference, especially suitable for time-varying complex work in the collection of vibration signals of the planetary gearbox. Liu.J[6] proposed a new feature extraction and fault diagnosis method for planetary gearboxes. The Euclidean distance method was used to extract 19 features, and the parameters which were sensitive to the health of the planetary gears were selected. The gearbox failure mode was analyzed by differential analysis. At present, relevant researches have been carried out on the fault diagnosis and prediction technology of planetary transmission structures. Representative researchers are from National Defense University of Science and Technology, Xi'an Jiaotong University, Beijing University of Science and Technology, University of Science and Technology of China, University of Electronic Science and Technology, Tsinghua University, Northwestern Industry. University, but there is still a big gap relative to the level of foreign research[7-9].

The research status at home and abroad shows that the fruitful research results have promoted the development of fault diagnosis technology for helicopter planetary transmission structure. In a certain sense, the problems faced by helicopter planetary transmission structure fault diagnosis are more clearly explained, which provides a research basis for subsequent research[10-12]. However, there are still some problems that need to be solved:

- Lack of systematic research methods
- Lack of planetary gear fault diagnosis
- Lack of targeted troubleshooting methods

Therefore, for the planetary structure characteristics of helicopter transmission system, the systematic research on the planetary structure fault monitoring technology of new helicopter transmission system has theoretical research significance and practical engineering value.

II. TEST CONDITIONS

A. Test equipment

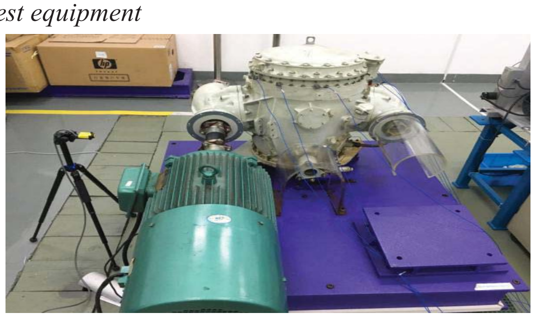


Figure.1 Helicopter main reducer structure

In this test, the existing X-type helicopter main reducer was used as the test platform, and the test platform was driven by an electric motor. The main reducer comprises a first-stage bevel gear, a secondary reduction bevel gear, a sun gear shaft, a fixed ring gear, a planetary gear, a tail rotor drive bevel gear, and a tail rotor drive driven bevel gear. The power is supplied by the electric motor and transmitted to the sun gear shaft via the primary and secondary deceleration bevel gears, which are then transmitted to the tail rotor drive bevel gears and planetary gears.

B. Test object

The test object is the main reduction planetary gear, as shown in the following figure. There are five planets in the main planetary gear of the X-type helicopter. Each planetary wheel is connected to the rotor shaft wheel through the bearing bear , and transmits the power of the sun gear shaft to the rotor, which also plays the role of deceleration.

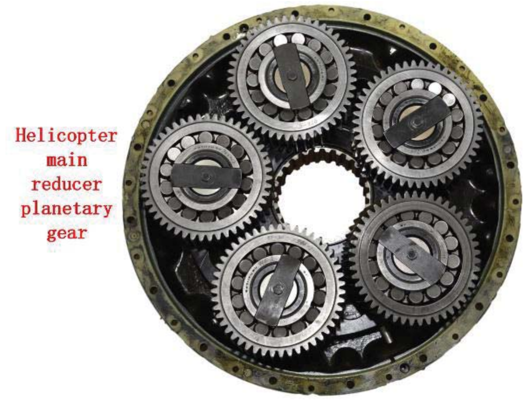
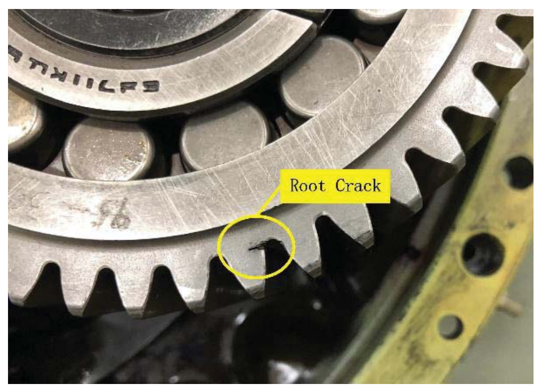
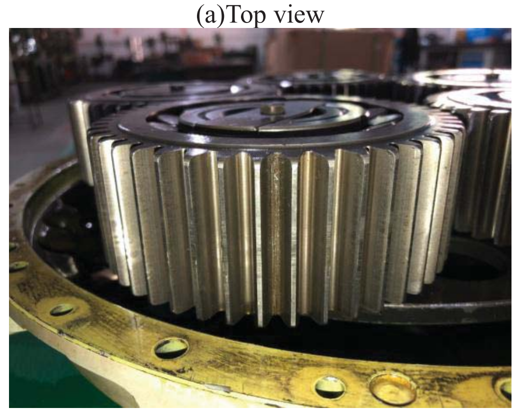


Figure.2 Test object planetary gear

One of the planetary gears is broken by wire cutting to form a certain degree of grooving, and the planetary gear root crack is simulated. The fault form is as follows:



(a)Top view



(b)Side view

Figure.3 Test object planetary gear fault

TABLE I. PLANETARY WHEEL INFORMATION TABLE

Gear type	Quantity	Number of gear teeth
planet	5	47
Sun gear	1	38
Stationary ring gear	1	132

C. Pilot projects

According to the type of test object and the conditions of this experiment, only one type of faulty part is processed.

The types of faults are shown in the following table:

TABLE II. PLANETARY GEAR FAILURE TYPE TABLE

Number	Fault object	Fault type	Remarks
1	Helicopter reduction Planetary gear	Root crack	normal
			Crack depth 0.5mm
			Crack depth 1mm
			Crack depth 2mm
			Crack depth 3mm

D. sensor layout

This test is only for planets and the sun gear and the inner ring gear are in a uniform horizontal plane, and there are only fixed points around the stationary ring gear. Therefore, it is necessary to find suitable fixing points around the stationary ring gear to install the sensor. It is planned to install sensors in three directions (X direction, Y direction, Z direction) along the ring gear as needed, as shown in the figures.

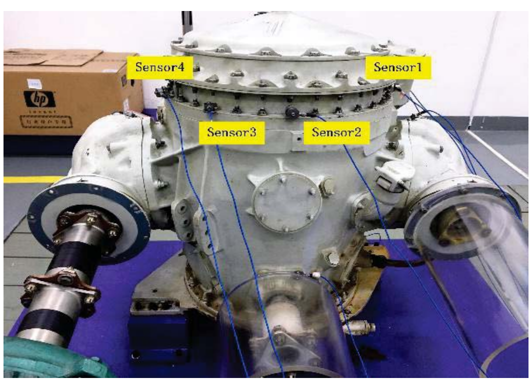


Figure.4 Straight nine main reduction test sensing layout 1

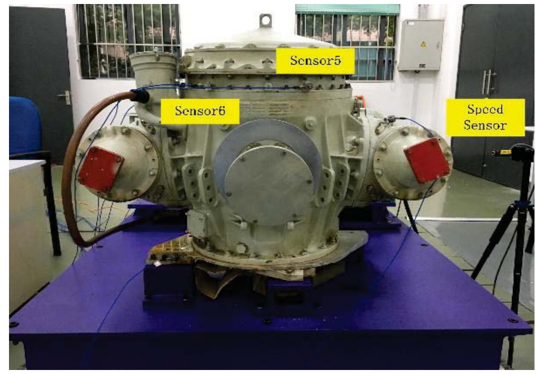
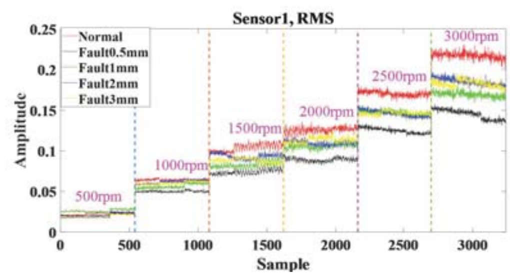


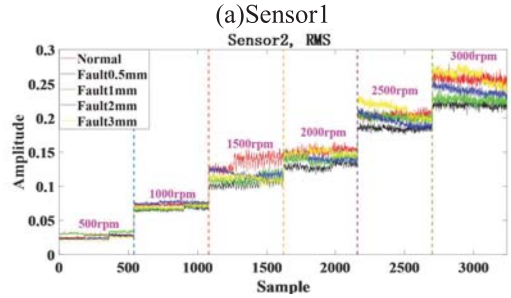
Figure.5 Straight nine main reduction test sensing layout 2

III. FAULT CHARACTERISTICS CONTRAST

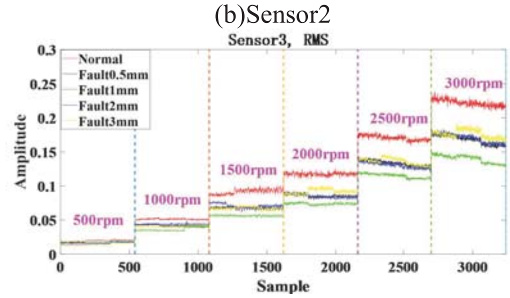
The time domain index is mainly reflected in the RMS value and the kurtosis value. The RMS comparison chart of each sensor under different speed states and fault states is as follows：



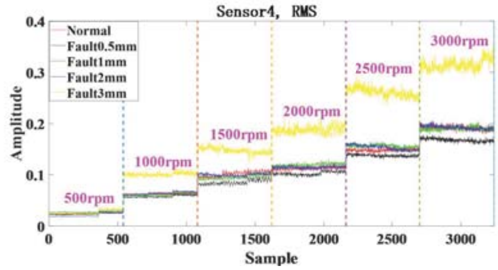
(a)Sensor1



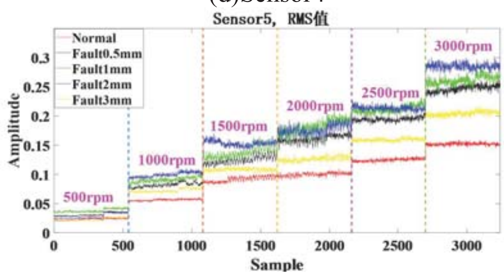
(b)Sensor2



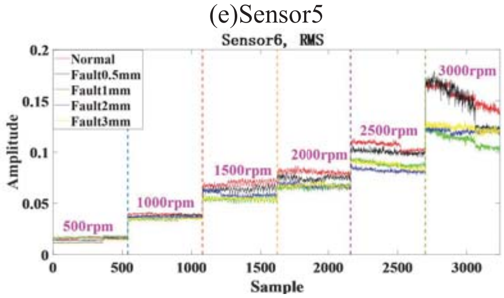
(c)Sensor3



(d)Sensor4



(e)Sensor5

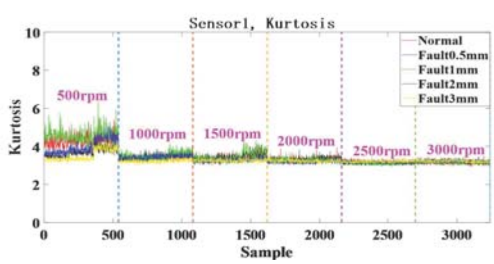


(f)Sensor6

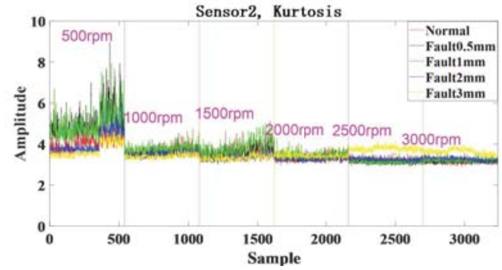
Figure.6 comparison chart of RMS in different failure and different speed

It can be seen from the figure that the RMS value of the fault data in sensor5 is larger than the RMS value of the normal data, and the higher the fault degree is, the larger the RMS value is. The values monitored by other sensors figures that the RMS value is greater than the RMS value of the fault data; however, the magnitude of the RMS value also has a linear relationship with the degree of fault, that is, a positive correlation or a negative correlation. At the same time, it also shows that the disassembly and installation of the planetary main gearbox of the helicopter main reducer also has a certain influence on the sensing signal. However, by comparing the RMS data of the fault depths of 1mm, 2mm, and 3mm, it can be seen that as the degree of failure deepens, the RMS value increases.

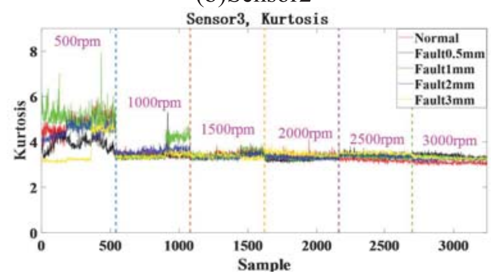
The kurtosis values are compared as follows：



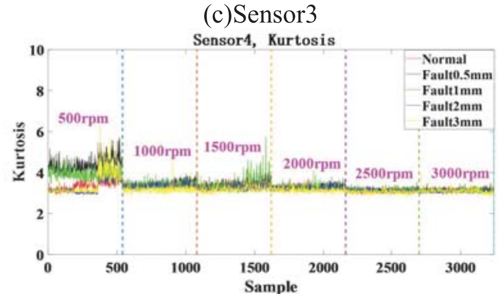
(a)Sensor1



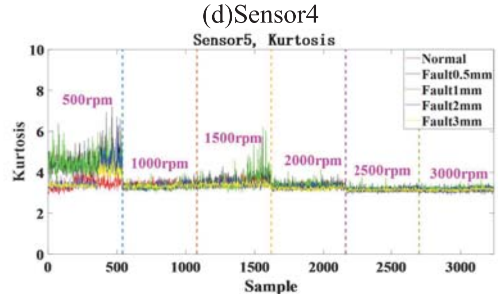
(b)Sensor2



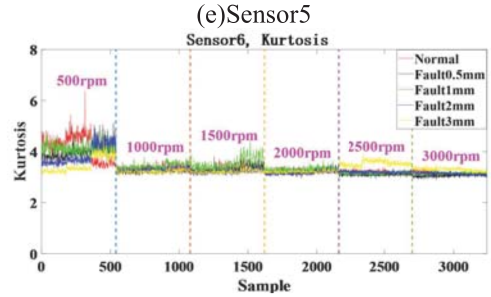
(c)Sensor3



(d)Sensor4



(e)Sensor5



(f)Sensor6

Figure.7 comparison chart of kurtosis value in different failure and different speed

By comparison, it was found that the kurtosis value was confusing when the speed was 500 rpm. This is because the main reduction used in this laboratory only provides one-sided power input and the other side does not provide power input; therefore, when the power input is 500 rpm in one side, the other side rotates or not rotate uncertainly, causing interference to the monitoring signal and instability. With the continuous increase of the rotational speed, the kurtosis values of all sensors' monitoring signals tend to be stable, and the value is about 3; therefore, if the influence of the interference signal on the characteristics of the monitoring signal is to be reduced, the monitoring data should be analyzed at a high rotational speed as much as possible.

IV. ROC CURVE AND THRESHOLD SETTING

Take the RMS value feature as an example to illustrate the ROC curve drawing and setting. Since the disassembly of the helicopter main reducer has an irreversible effect on the overall structure, the characteristics of the normal state and the characteristics of the fault state cannot be concluded by comparing, so this example will compare the failure expansion trend to illustrate the ROC curve and to get the state threshold.

As shown in the figure below, the RMS feature distribution is shown in the fault depths of 0.5mm and 2mm respectively. It can be seen from the figure that regardless of the degree of fault, the features follow the Gaussian distribution, and the greater the fault depth, the further the deviation will move to right. The blue line and the red line in the figure are the distribution curves of the Gaussian distribution according to the RMS characteristic values under different fault degrees; but the characteristics have a certain degree of overlap and cannot be distinguished.

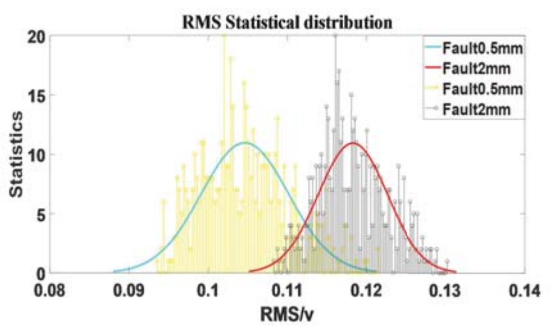


Figure.8 RMS feature distribution comparison of Fault-0.5mm and Fault-2mm

As shown in the figure above, the threshold is set within the range of the RMS value, with the Fault 0.5mm fault as the reference state and the Fault2mm as the fault state. The false alarm rate in the reference state and the monitoring rate in the fault state are calculated respectively. And establish a false alarm rate and monitoring coordinate system, as shown below：

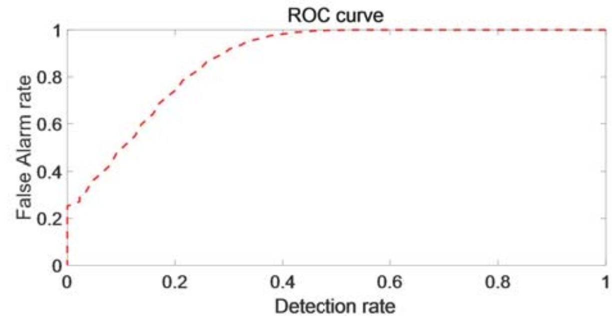


Figure.9 RMS characteristic ROC curve of Fault-0.5mm and Fault-2mm

From the ROC curve, as the threshold increases within the eigenvalue range gradually, the false alarm rate and the monitoring also change accordingly; the criterion for determining the threshold is the curve point closest to the point where the monitoring rate is 1 on the ROC curve, as shown in the following figure：

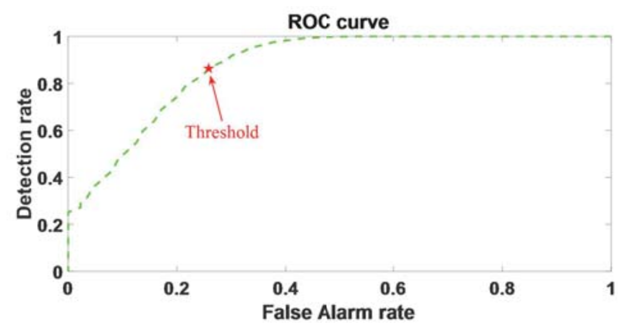


Figure.10 RMS characteristic ROC curve of threshold Fault0.5mm and Fault2mm

In the above figure, the threshold value of the ROC curve closest to the point 1 is as shown in the following figure. The points shown in the figure are the threshold set points in the two states.

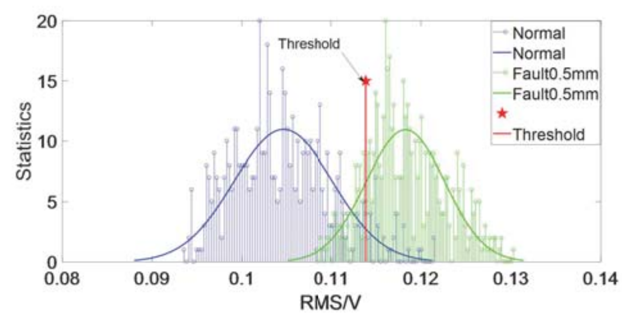
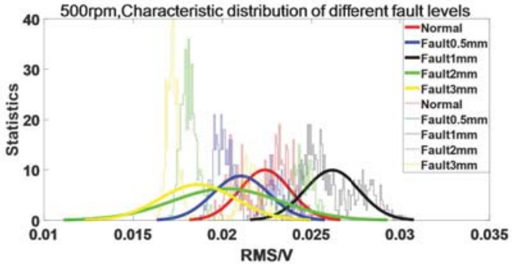


Figure.11 Fault0.5mm and Fault2mm RMS Feature Threshold Settings

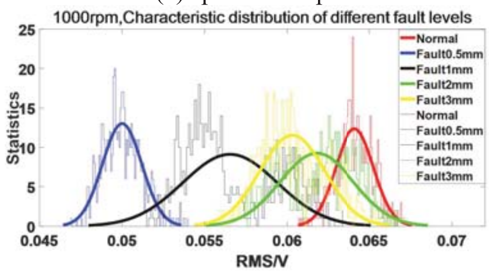
3 Distribution of features

According to the ROC curve method mentioned in the previous section, the characteristic thresholds of different fault levels are set. Now, the distribution of a certain characteristic value of the planetary gears under all working conditions and different fault degrees is summarized. Taking the sensor No. 1

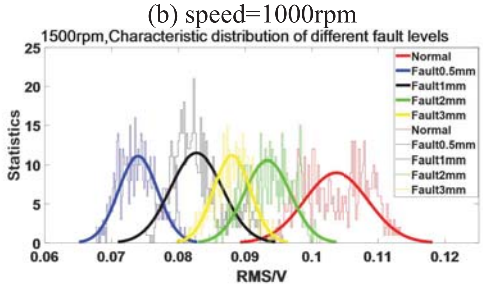
sensor as an example, the characteristics of the distribution at different speeds are shown below.



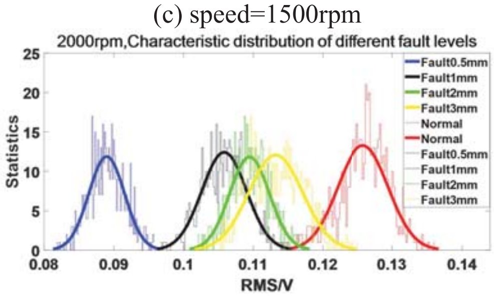
(a) speed=500rpm



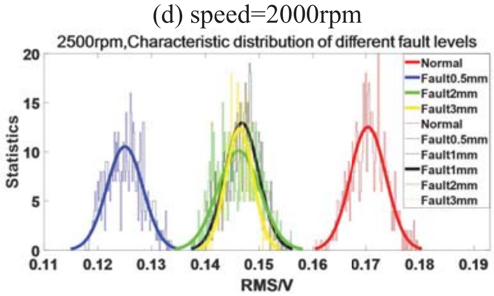
(b) speed=1000rpm



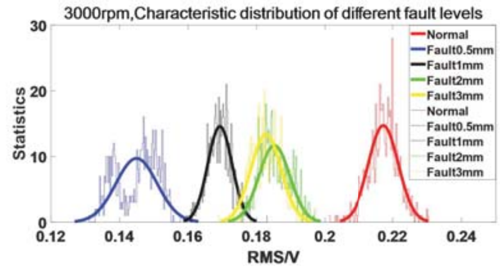
(c) speed=1500rpm



(d) speed=2000rpm



(e) speed=2500rpm



(f) speed=3000rpm

Figure.12 Figure fault expansion trend feature distribution map at different speed

According to the distribution of the above figure, the characteristic distribution under normal conditions is larger than that in the fault state, which indicates that the disassembly of the reducer has irreversibly affected the structural integrity of the reducer. Shielding the distribution of features under normal conditions, only considering the distribution of fault extension trends under multiple operating conditions, the increase in rotational speed has a directly impact on the trend of the characteristics, such as positive correlation; the continuous deepening of the fault trend is also positively correlated with the distribution of faults. From the analysis of the feature distribution in the figure, the overlap of the fault-2mm and fault-3mm feature distributions of the fault depth is higher, which is related to the fault production; the failure of the fault-3mm production process may be the main factor of this influence.

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