Fault diagnosis of rolling bearing based on time and frequency domain analysis and EMD

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***Abstract*—Prognostic and health management (PHM) technology is the use of a large amount of condition monitoring data and information, with the help of all kinds of fault model and artificial intelligence algorithms monitoring, diagnosis, prediction and management of the health status of the equipment technology, by predicting the problems and reliable working life, improving the safety of equipment, minimizing the fault effect, this article in rolling bearing, using Labview software construction time domain analysis program, the analysis of three kinds of condition from different perspective (35Hz12KN/37.5Hz11KN/40HZ10KN)under the rolling bearing, Finally, Matlab software was used for frequency domain analysis and empirical mode decomposition (EMD), and the inherent modal function and vibration signal spectrum were extracted to find out the fault characteristic frequency band, which provided a basis for bearing fault diagnosis under different loads.**

Keywords-component; PHM;Time domain analysis;Frequency domain analysis;Empirical Mode Decomposition;feature extraction(key words)

I. INTRODUCTION

As ‘made in China 2025’ slogan, adhere to the ‘innovation drive;quality first; the green development; structural optimization.’ the basic policy, however, compared with the advanced world level, China's manufacturing sector is big enough but not strong, more and more attention to the quality of the product manufacturing problems, failure prediction and Health Management Technology (Prognostic and Health Management, PHM) also arises at the historic moment, the prediction is one of the key technology of PHM, through the use of a large number of real-time data in the process of monitoring,Various intelligent algorithms are used to scientifically evaluate the current health status of the equipment, so as to improve the maintenance support efficiency of the equipment. The former ‘passive’ maintenance status is changed to ‘active’ maintenance, and the ‘situation maintenance’ is changed to ‘situation maintenance’.Before the failure of the equipment, it can greatly extend the service life of the equipment, and also improve the economic efficiency, which has positive practical significance in improving the quality level of the manufacturing industry.

Rolling bearing[1][2][3] is one of the most common and the most vulnerable key parts in the manufacturing industry of rotating machinery equipment, known as the ‘industrial joint’, rolling bearing is also one of the 11 categories of specific revitalization machinery products identified by the state, as a basic part it requires high precision, good fit.As an accessory, it is widely used in military, aerospace, satellite, vehicle and other fields.Many faults of rotating instruments are associated with rolling bearings, which are damaged in various forms, such as fatigue spalling, surface wear of inner and outer rings of bearings, bearing breakage, bearing cage or rolling body fragmentation, etc. The rolling bearing has the characteristic of great dispersion of life, but the service life of the bearing produced under the same conditions of the same batch, the same production line, person, machine, material, method and ring is quite different, and the traditional ‘regular maintenance’ cannot maintain the equipment scientifically. Therefore, it is necessary to monitor the condition of rolling bearing and evaluate its service life. Turning ‘regular maintenance’ into ‘condition maintenance’ can guarantee the quality of mechanical products to the maximum extent and avoid excessive economic losses.

For bearing fault diagnosis is the earliest scholars from the United States, aiming at the existing problem of the bearing fault is proposed by using acceleration sensor to collect the bearing vibration signal, David Brie [1]simplified the rolling bearing mechanism with a linear time-varying model, making it easier to grasp the internal vibration law of the bearing. G.K. Chatuvreid and.D.W.Thomas[2]. The proposed adaptive noise reduction technology for bearing fault diagnosis (ANC) in the statistical analysis method is better in fault diagnosis, Professor LEI yaguo[3]and LI hao[4] find the wavelet transform is compared with the ordinary observation method has obvious superiority in the signal processing, it not only inherited and developed the thought of localization, short time Fourier transform (STFT) and overcome the frequency change the window size does not change with frequency and other

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shortcomings, can provide fault diagnosis analysis from the perspective of time or frequency perspective collected vibration signal of a method, It is an ideal tool for signal time rate analysis and frequency analysis.

II. INTRODUCTION TO BASIC THEORIES

A. Time domain analysis

Bearing vibration generated during running reflects the service state of the bearing, and when this state changes, the corresponding vibration signal will also change. There are many ways to deal with vibration signal, but time-domain analysis is the earliest and most basic signal analysis method.We can judge by the time-domain parameters, and compare the collected time-domain parameters with the bearing time-domain parameters under normal conditions, so as to judge whether the bearing has faults.[5]

Assuming that sampling results in a set of discrete vibration signals, { x_i }, {i =1,2,3...}, the time domain waveform reflecting bearing features are more intuitive and clear. It is a dimensional index, and the specific waveform index S can be expressed as:

$$S = \frac{X_{rms}}{|\overline{X}|} \tag{1}$$

$$X_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{X})^2} \tag{2}$$

X_{rms} is the root mean square value and $|\overline{X}|$ is the absolute mean amplitude.

In the time domain, characteristic parameters can be divided into dimensionless parameters such as mean value, root mean square, peak value, peak-to-peak value, standard deviation and variance, or dimensionless parameters can be obtained by the ratio of dimensionless parameters to dimensionless parameters.

In general, for the convenience of later time domain analysis, we will conduct a centralized processing of the vibration signal. In order to describe the stability of the signal amplitude, we will introduce the mean value $\overline{X}$, maximum value $X_{\max}$, minimum value $X_{\min}$, as well as the peak-to-peak value X_{p-p} , variance S and root mean square value X_{rms}

$$\overline{X} = \frac{1}{N}\sum_{i=1}^{N} X_i \tag{3}$$

$$X_{\max} = MAX\ \{|X_i|\} \tag{4}$$

$$X_{\min} = MIN\{|Xi|\} \tag{5}$$

$$X_{p-p} = MAX\{X_i\} - MIN\{X_i\} \tag{6}$$

Variance is generally used to describe the size of quality fluctuation in the quality industry, and it can also be used as a constant to describe the size of off-center position:

$$S = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{X})^2 \tag{7}$$

B. Frequency domain analysis

Generally speaking, signals that can be directly observed or recorded are independent of time[6]. Time-domain analysis method observes input signals from the perspective of time, but cannot reveal the frequency composition relationship of signals. While frequency-domain analysis method can study the frequency structure of signals and the amplitude and phase relationship of each frequency component. Especially for rolling bearings, when the contact surface of rotating instruments is damaged, it will cause periodic impact force, which is very easy to change the vibration frequency. Therefore, frequency domain analysis method is needed to make more accurate judgment. Frequency-domain analysis methods are commonly used: power spectrum analysis, cepstrum analysis, self-spectrum analysis, Fourier spectrum and so on. The FFT transform of the signal and the power spectrum formula is:

$$X(f) = \int_{-\infty}^{+\infty} x(t)e^{-i2\pi ft}dt \tag{8}$$

$$G_x(f) = 2S_x(f) = 2\int_{-\infty}^{+\infty} R_x(\tau)e^{-i2\pi f}td\tau \tag{9}$$

$R_x(\tau)$ is the auto-correlation function and $S_x(f)$ is the self-power spectral density function.

C. Frequency domain analysis

Empirical mode decomposition (EMD) adaptively decomposes the nonlinear and non-stationary rolling bearing vibration signals into a series of smooth natural modal functions[7], and the decomposed components contain local characteristic signals of rolling bearing vibration signals in different time scales, which is better than the traditional Fourier transform method.The specific algorithm is as follows:

a) for any signal; firstly; all the extreme points on the signal are determined, and then all the maximum points and all the minimum points are connected with a curve.

b) These two curves are taken as the upper and lower envelope of $S(t)$ respectively. The mean value of each point of the upper and lower envelope is denoted as m , and the subtraction of $S(t)$ and m is denoted as h

$$S(t) - m = h \tag{10}$$

c) h will be regarded as new $S(t)$, repeat the above operation until when h certain conditions (such as h small enough) are met, $c1$ will be regard as $IMF_1 t$

$$S(t) - c1 = r_1 t \qquad (11)$$

Regard $r_1 t$ as new $S(t)$ and repeat the process above, in turn get $IMF_2 t$,c2 , $r_2 t$, $IMF_3 t$, c3 , $r_3 t$,......The procedure terminates when cn or $r_n t$ given termination condition is satisfied (the remainder is small enough or becomes a monotone function)

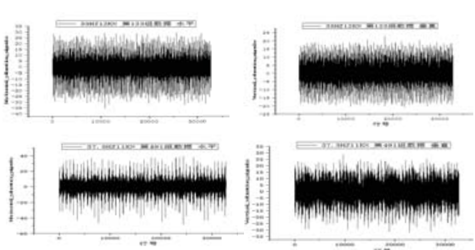
$$S(t) = \sum_{i=1}^{N} IMF_i(t) + r_n t \qquad (12)$$

The empirical mode decomposition method can be used to decompose the signal into two parts through modal analysis.Different frequency components are separated, and the frequency peaks of the original signal combination are decomposed one by one, so as to enlarge the smaller frequency peaks.By decomposing the monitoring signals, the model information is enriched and the modal characteristics are more obvious.

III. THE EXPERIMENT INSTRUCTIONS

XJTU-SY bearing data-sets are provided by the Institute of Design Science and Basic Component at Xi'an Jiaotong University(XJTU), Shaanxi, P.R. China and the Changxing Sunyoung Technology Co., Ltd. (SY), Zhejiang, P.R. China.The platform can carry out all kinds of rolling bearing and bearing are accelerated degradation experiment, bearing the full life cycle of monitoring data, this experiment object to LDK UER204 rolling bearing, a total design three kinds of experiment conditions, (35 Hz10KN / 37.5 Hz11KN / 40 Hz12KN), each test under the condition of 5 bearing, the sampling frequency is set to 25.6 KHz, sampling record total of 32768 data points, the sampling period of 1 min, bearing has been collected from the intact until to start at different positions of the bearing vibration signal fault occurs.Table 1 is the horizontal and vertical vibration signal images of LDK UER204 rolling bearing under different kinds of working conditions from initial state to failure.

Horizontal vibration **Vertical vibration** **Fault element**



Outer race

Inner race

Figure I： LDK UER204 rolling bearing under different kinds of working conditions

As can be seen from the figure I, the bearing under three working conditions has different failure modes, among which the failure of the outer ring is more frequent. However, the specific details cannot be analyzed by simple vibration images. Therefore, a more professional analytical approach is needed.

IV. TIME DOMAIN ANALYSIS USED TO EXTRACT FEATURES

According to the time domain diagram analyzed by LabView software, it can be seen that the root mean square, peak value, peak-to-peak value and variance of the bearing under three kinds of working conditions are increasing under the load movement in different time. The variance is almost 333 times larger.The vibration signal unfolds periodically.

TABLE I . .BEARING CHARACTERISTIC PARAMETERS UNDER DIFFERENT WORKING CONDITIONS

Bearing	Condition	Root mean square	peak	variance	Fault element
Bearing 1	1-1	0.563	2.354	0.317	
	1-123	7.268	29.70	52.82	Outer race
	2-491	7.160	39.54	51.27	Inner race
	3-2538	9.125	29.23	83.26	Outer race
Bearing 2	1-1	0.619	3.902	0.384	
	1-161	6.964	35.02	48.50	Outer race
	2-161	7.664	41.48	58.74	Inner race
	3-2496	5.749	21.54	33.04	Inner and outer race
Bearing 3	1-1	0.495	1.896	0.245	
	1-158	3.969	20.45	15.75	Outer race
	2-533	5.042	20.39	25.41	cage
	3-371	4.959	32.01	24.59	Inner race
Bearing 4	1-1	0.462	1.667	0.213	
	1-112	2.051	54.41	4.285	cage
	2-42	6.331	21.69	40.07	Outer race
	3-1515	4.281	24.82	18.33	Inner race
Bearing 5	1-1	0.973	3.877	0.946	
	1-52	9.217	41.74	84.94	Inner and outer race
	2-339	8.449	36.80	71.40	Outer race
	3-114	7.021	27.21	49.29	Outer race

Can be seen in the table I rolling bearing fault of variance of different parts is different also, when the outer ring fault occurs, the variance is compared commonly big, about fluctuations between 40-70, and when there is a single cage or other parts of the failure is in commonly 4-50 or so, to some extent, it also tell us, we can through the variance analysis of the vibration signals of the general fault.

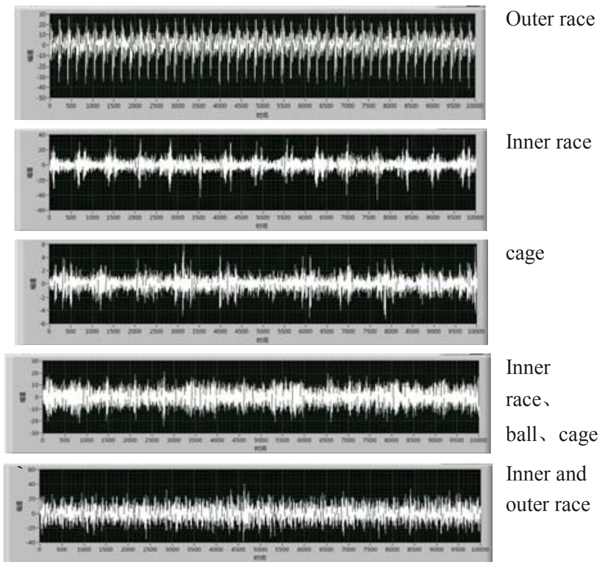


Figure II：Comparison of time domain diagrams of different fault location(horizontal vibration)

It can be seen from figure II that the time-domain diagrams of different fault locations are also slightly different. The time-domain diagrams of the vibration signals of the outer ring faults have a short period, and it can be seen that the wave peaks are relatively dense.The vibration signal of the inner ring fault has a longer period than that of the outer ring.It's also relative to having rules to follow.However, the vibration signals of the damaged bearings shown in the figure are disorderly and have no rules to follow.

In practical application, a large number of tests are needed to determine the time domain parameter range of the normal state of the bearing, so as to ensure that there is no misjudgment and misjudgment, so that the faulty bearing can be timely judged and repaired.

V. BEARING WEAR ASSESSMENT BASED ON FREQUENCY DOMAIN ANALYSIS

In this paper, Matlab software is used to analyze the frequency domain of rolling bearing vibration signal, and different frequency domain diagrams are obtained through relevant algorithms for analysis, so as to classify and judge the fault location according to the difference in spectrum amplitude or position of different fault locations.

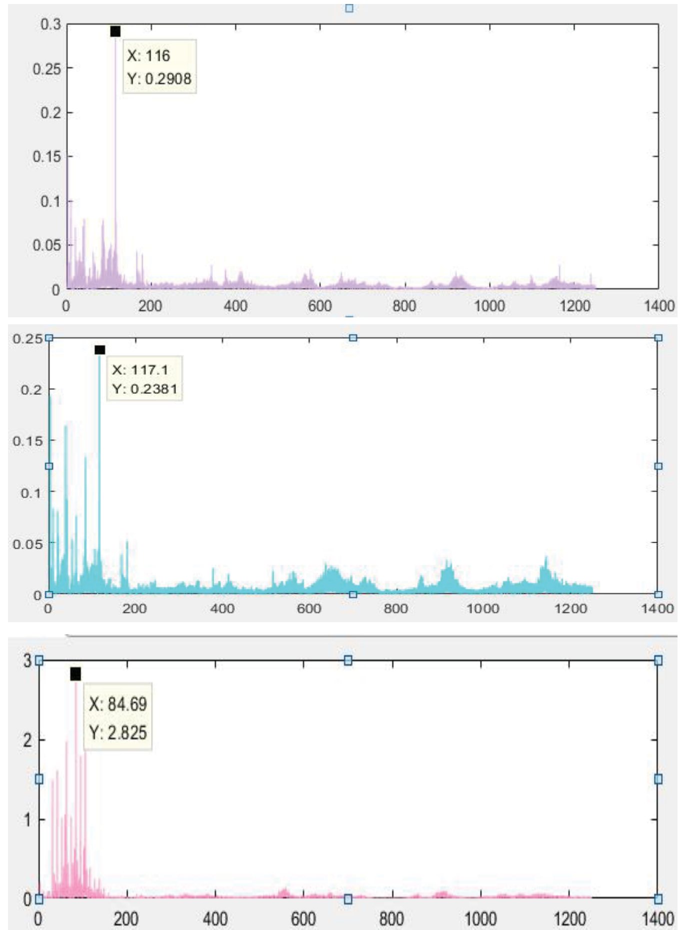


Figure III ：Comparison of frequency spectrum of rolling bearing in different time periods

For mechanical faults, spectrum analysis has strong applicability and can simply and effectively reveal the cause of failure. According to the frequency spectrum of rolling bearing in different time periods, it can be seen that the amplitude of low-frequency signal of rolling bearing changes greatly and the number of spectral lines increases significantly under the condition of rubbing. Until the bearing failure amplitude fluctuation range increased by nearly 10 times. The failure mode of rolling bearing shown in the figure is outer ring wear, and there are obvious spectral lines at 31.74Hz of outer ring wear and its double frequency of 63.48Hz. And the other spectral lines can be found at 2 times the frequency of the corresponding spectral lines.

VI. VIBRATION SIGNAL ANALYSIS OF ROLLING BEARING BASED ON EMPIRICAL MODE DECOMPOSITION (EMD)

This paper intends to use Matlab software to carry out the inherent modal decomposition of rolling bearing vibration signal, and obtain the bearing's inherent modal function by decomposing the vibration signal of rolling bearing, and use the spectrum diagram drawn by Fourier transform.

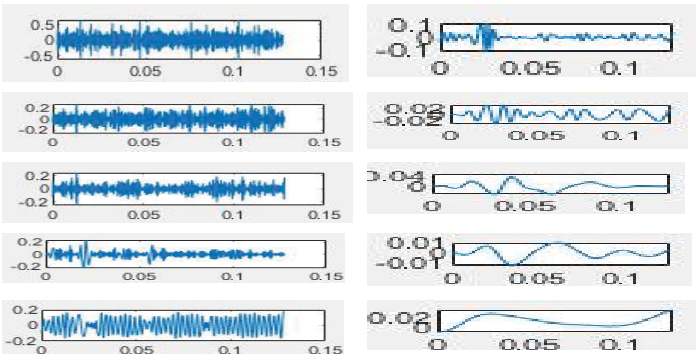
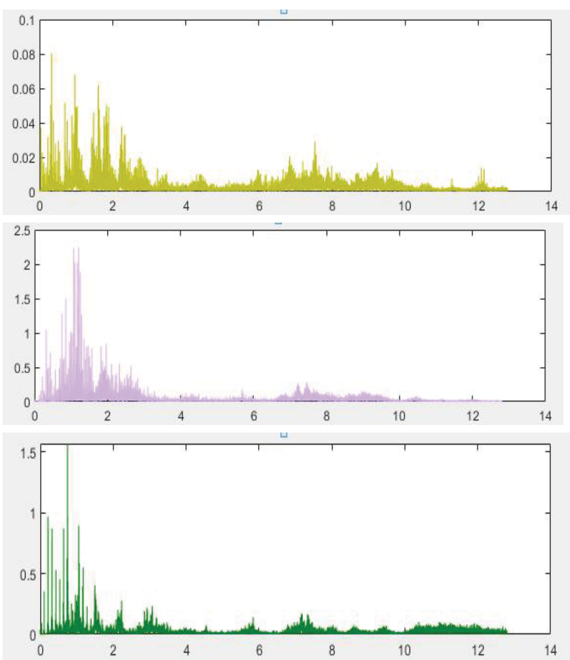


Figure IV： Imfs spectrum of rolling bearings



health

Outer race

Inner race

Figure V: Imf spectral unit of rolling bearing under different conditions ($\times 10^4$ Hz)

It can be found from the spectrum diagram of different fault parts that no matter the outer ring fault or the inner ring fault, the parts where the amplitude changes the most are all concentrated in the low frequency. In the early stage, the amplitude between 0.2KHz-1.1KHz is not obvious, and then the amplitude increases with the increase of the wear degree of the rolling bearing. The peak value of 1.1KHz always exists, and the peak value between 0.5KHz and 1.6KHz occurs when the bearing fails, and exists in the middle and late period.

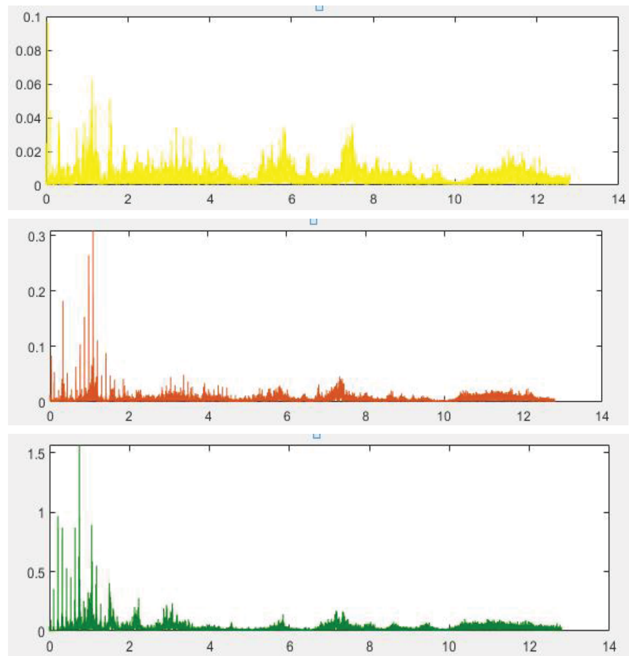


Figure VI： Comparison of IMF1 spectral images under different time periods($\times 10^4$ Hz)

By looking at different times of imf1 vibration signal spectrum, we can find that with the increase of time bearing wear between 0 and 1KHz amplitude is not too big change, and change to late amplitude increased nearly 10 times, thus we can infer that 1KHz to 1.4KHz between the first intrinsic mode function as the rolling bearing wear and changed its inherent vibration mode, so the amplitude increase with the wear and rolling bearing. The energy distribution between 0.4KHz and 2.1KHz has a smaller amplitude in the early stage and a larger distribution in the later bearing wear stage, so we can focus on the analysis of this frequency band in the future.Moreover, it can be predicted that the wear of rolling bearing leads to the change of the bearing's inherent modal information.

VII. CONCLUSION

In recent years, vibration signal analysis has achieved great success in the field of fault diagnosis of large rotating machinery, because the rolling bearing of rotating instruments has a typical fault feature despite a large life dispersion. The rubbing performance is higher at low frequency, the looseness performance is higher at high frequency, and the characteristics of different faults are quite different. From the perspective of time domain analysis, we can distinguish the fault location according to the difference in the period size of the time domain waveform formed by different faults. From the spectrum of vibration signal, the characteristic spectrum of the fault is usually the integral multiple (twice of the outer ring) or the fractional multiple of the rotational speed, so the whole period sampling is needed. In general, the connection between the time-domain analysis and the frequency-domain analysis is established through the Fourier transform (FFT). The more accurate fault characteristic frequency can be obtained.

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