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Fault Feature Extraction of Diesel Engine Piston and Piston Pin Based on EEMD-AR Spectrum

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Abstract

A new fault diagnosis method for diesel engine piston and piston ring wear combined with EEMD and AR is proposed. The vibration signal of normal working condition, piston and piston ring wear under three working conditions was collected. The IMF component was obtained by EEMD decomposition, and the AR spectrum of IMF1~IMF6 component accounting for 97.13% of the total energy of the signal was analyzed to extract the fault. Information. The analysis results show that the AR spectrum of IMF2 can more effectively reflect the fault characteristics. The diagnostic method based on EEMD-AR can correctly judge the operating conditions of diesel engines.

Keywords

EEMD; AR spectrum; Diesel engines; Piston; Piston pin; Troubleshooting.

1. Introduction

The vibration generated by the internal components of the diesel engine such as the piston and the connecting rod is synthesized and transmitted to the diesel engine block. The vibration signal contains rich component information, and the vibration signal can be used to diagnose the running state of the internal moving component of the diesel engine. However, diesel engine operation involves complex reciprocating motions and rotational motions, so the vibration signal of the cylinder is a typical unsteady signal with complex frequency components [1]. Although the traditional Fourier spectrum analysis has achieved great success in dealing with steady-state signals, it is only based on the signal's stationarity, it can only reflect the characteristics of the signal from the time domain or the frequency domain, and cannot simultaneously consider the signal in the time domain and frequency. Localized features and overall appearance of the domain [2]. Modern signal processing methods such as short-time Fourier transform, Wigner distribution, and wavelet transform describe the time-varying of non-stationary signals to varying degrees, but in the final analysis, they are based on Fourier transform. The choice of basis function does not depend on the information of the signal itself [3]. The EMD method is an adaptive and efficient signal decomposition method suitable for processing nonlinear and non-stationary signals [4]. It extracts the IMF from the target signal by "screening". However, when the data is not pure white noise, some scales will be lost, and modal aliasing will occur [5]. The so-called modal aliasing, that is, an IMF component includes a signal with a large difference in scale, or a signal of a similar scale appears in a different IMF component. The reason for modal aliasing is the discontinuity of the signal. This discontinuity not only causes severe aliasing in the time-frequency distribution, but also makes the individual IMF components lack physical meaning [6].

EEMD solves the shortcomings of the EMD method. When the target signal is added with evenly distributed white noise, the noise added in each test is different, so when the average of the test is used, the noise will be eliminated. The overall mean will eventually be considered a

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true result, the only lasting part of the signal is the signal itself, and the multiple tests added eliminate the added noise [7].

In this paper, the EEMD method is used to deal with the vibration signals under normal conditions, piston and piston pin failure, and the 7th-order IMF component obtained after decomposition is analyzed by AR spectrum to obtain the energy characteristics of the band under normal conditions, piston and piston pin failure.

2. EEMD Method and AR Spectrum

2.1. EEMD Method and IMF Component

EEMD adds white noise to the original signal to improve the distribution of extreme points andovercome the modal aliasing of EMD. Since the added white noise is an uncorrelated random sequence with zero mean value, the added external noise can cancel each other out after multiple averaging, which eliminates its influence on the original signal [8]. The EEMD steps are as follows:

1) Given an original signal x(t), add a different white noise sequence $n_j(t)$, (j=1, 2, 3, ..., M), where j is the number of times the white noise is added;

$$x_j(t)=x(t)+ n_j(t) \tag{1}$$

Where: $x_j(t)$ represents the signal after the jth addition of white noise.

2) Decompose $x_j(t)$with EMD to get I (IMFs) $C_{i,j}$(i=1,2,3,...,I), where $C_{i,j}$ represents the j-th join white Noise amplitude.

3) If j < M, let j = j + 1 repeat step 2;

4) Perform the average averaging operation on the above IMFs, and the resulting IMF is:

$$C_i = (\sum_{j=1}^{M} C_{ij})/M \tag{2}$$

Where: C_i represents the i IMF obtained by EEMD, and C_(i, j) represents the i-th IMF decomposed after the jth addition of the white noise amplitude, and M represents the total number of times.

5) Output C_i (i = 1, 2, 3, ..., I) as the i-th IMF obtained by EEMD.

The EEMD method gradually separates the IMF components from the high frequency to the low frequency from the original signal, and obtains the narrowband components of the original signal with different time scales to realize the adaptive multi-scale of the signal data [9].

2.2. AR Model

AR model is the most basic and widely used mathematical model in time series analysis. It not only condenses the characteristics and working state of the system, but also has the extensional characteristics of the observed data. It can not only be used for fault diagnosis, but also for early prediction of fault hidden dangers [10]. Based on the AR model of IMF, the EEMD of vibration signals $x_1(t)$, $x_2(t)$ and $x_3(t)$ under normal state, piston and piston pin fault is decomposed, then the c_1, c_2, c_3,..., c_n ,satisfying IMF component is extracted, and then ar model is established for each component.

$$c_i(t) + \sum_{k=1}^{m} \varphi_{ik}\, c_i(t-k) = e_i(t) \tag{3}$$

Where: φ_{ik}: model parameters of the AR model of component c_i (t);

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$e_i(t)$: the residual of the AR model;

m: the model order of the AR model.

3. Vibration Test of Diesel Engine Piston and Piston Pin Failure

Wear is one of the common faults of diesel engines. Excessive wear between piston liners can cause the pressure drop in the cylinder to reach the working pressure, the oil is diluted by the fuel, the oil is burned, and even the cylinder is damaged. This seriously affects the working performance of the diesel engine. 11]. When the piston pin and the small end of the connecting rod are normally matched, the impact force and vibration generated by the piston pin are small. However, excessive wear causes the piston pin to generate a large impact force and vibration after the gap is abnormal. Therefore, understanding the current working conditions of the piston and piston pin is of great significance for the safe and stable operation of the diesel engine. In this paper, the third piston piston pin and piston wear fault of the Sterling diesel engine are obtained. The vibration characteristics of the two faults are obtained. The piston wear test adopts the normal piston pin. Similarly, the piston pin wear test uses the normal piston.

In general, the magnitude of the vibration amplitude of the measuring point is proportional to its distance from the source and also to the characteristics of the transmission channel. The farther the distance is, the more the signal is attenuated; the worse the transmission channel characteristics, the more the signal attenuation in a particular frequency band is [10]. Through many tests, it is found that the acceleration vibration sensor is worn at the top of the third cylinder head, the third cylinder of the upper part of the cylinder, the left and right positions of the third cylinder of the oil bottom casing and the cylinder joint, and the lower part of the oil bottom casing. The position of the third cylinder is sensitive. In this paper, the data of the sensor placed on the top of the cylinder head is selected for analysis. The 60A01 ICP industrial acceleration vibration sensor produced by American PCB Company is used. The stability of the sensor is less affected by the environment.

Because the sensitive speed corresponding to the piston and piston pin wear fault is unknown, the acquisition system is designed with four speeds of 800r/min, 1300r/min, 1800r/min and 2100r/min [10]. It is found that the 1800r/min speed can better reflect the wear characteristics of the piston and piston pin.

The vibration signal spectrum of this type of diesel engine is about 4000Hz. According to the Shannon sampling theorem and considering the margin, the sampling frequency is determined to be 12.8kHz and the sampling point is 16384, so that the diesel engine can collect 8 working processes even at the minimum speed.

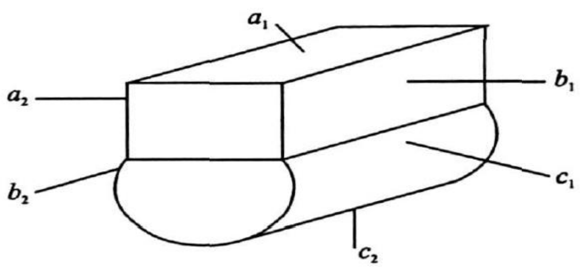

Figure 1. Acceleration vibration sensor installation position

Figure 2 shows the three sets of vibration signals of the engine normal state, piston wear and piston pin wear a, b, c collected by the acceleration vibration sensor at the top of the cylinder head and the diesel engine speed of 1800r/min. Figure 3 is a Fourier amplitude spectrum of the vibration signal of a diesel engine under three operating conditions. Piston pin wear faults can be diagnosed from the Fourier amplitude spectrum, but normal conditions and piston wear faults are difficult to diagnose.

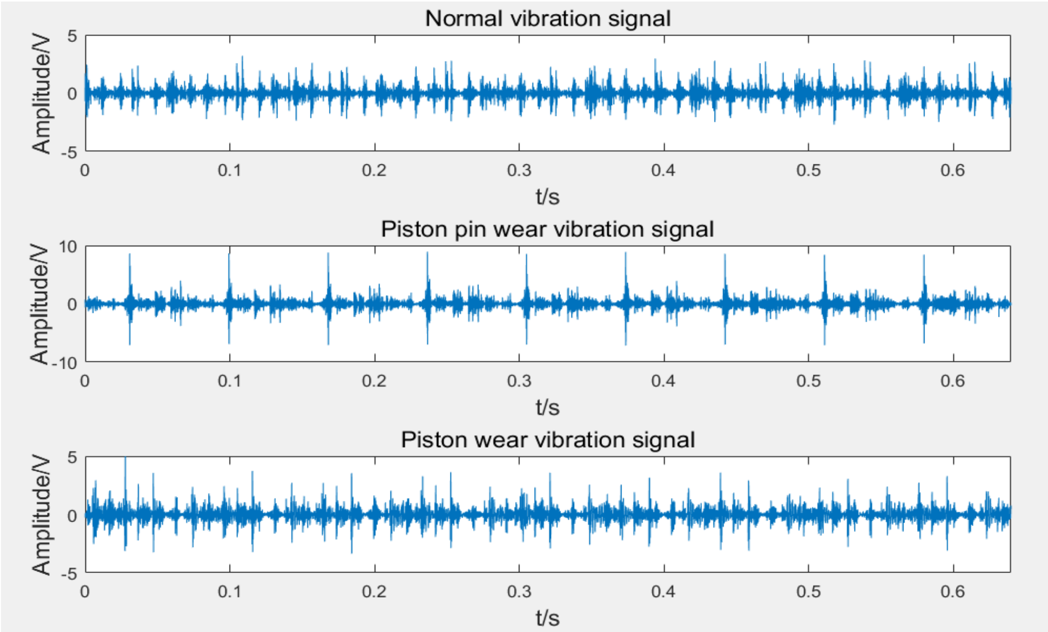

Figure 2. Diesel engine vibration signal under three working conditions

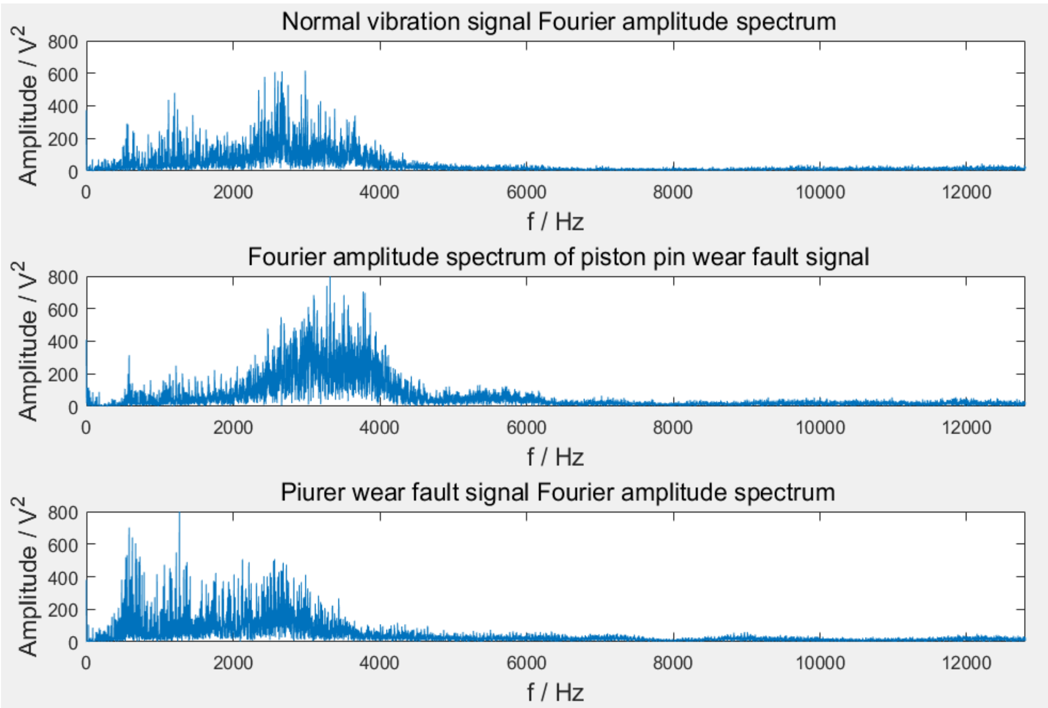

Figure 3. Fourier amplitude spectrum of diesel engine vibration signal under three working conditions

4. EEMD Decomposition and AR Spectrum Analysis

The vibration signals collected under the three operating conditions are decomposed by EEMD to obtain the IMF components and residual components of each order. Among them, the standard deviation of the auxiliary white noise is 0.3 times of the original signal, M=100, and

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the piston pin wear failure EEMD is decomposed as shown in Fig. 4. The fault vibration signal is decomposed into 14 orders from high frequency to low frequency IMF component and 1 The residual component, EEMD, weakens the modal aliasing phenomenon and effectively separates the various components of the signal. The first 6-order IMF components of c1~c6 in Fig. 4 are calculated and found to account for 97.13% of the total energy, and the signal intensity of the IMF component gradually decreases with the increase of the order, so that the main information is guaranteed without loss. Under the premise, in order to reduce the amount of calculation, the first 6 orders of IMF components are selected for AR spectrum analysis. The first 6 orders of IMF components are shown in Fig. 5.

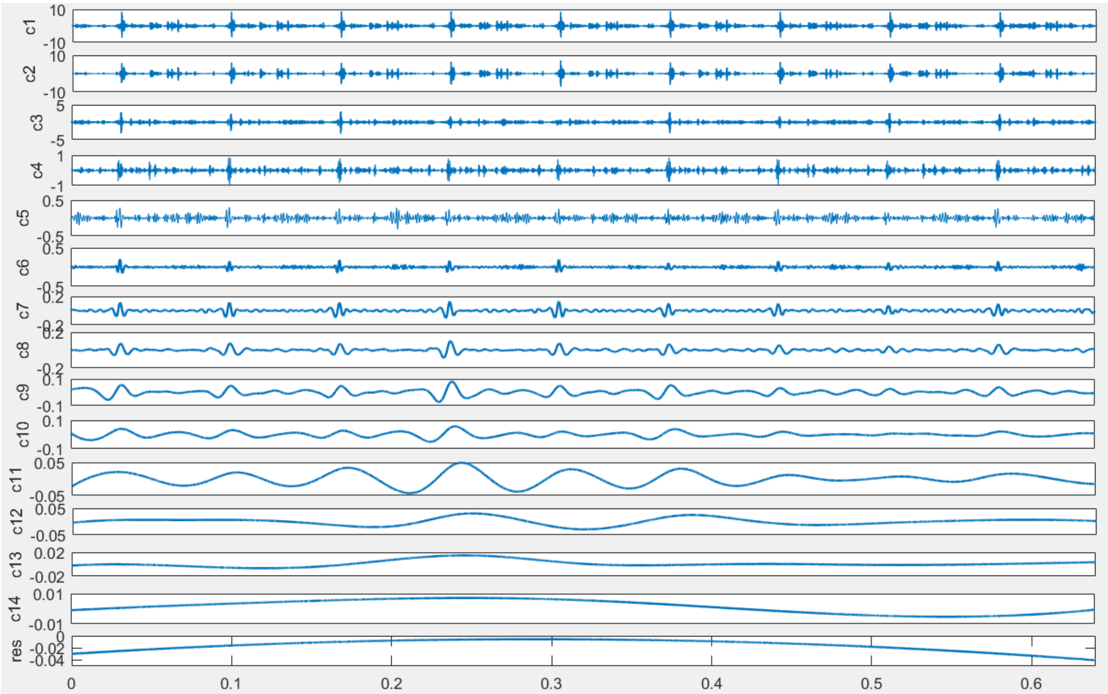

Figure 4. IMF component and residual component of each stage after piston pin failure is decomposed by EEMD

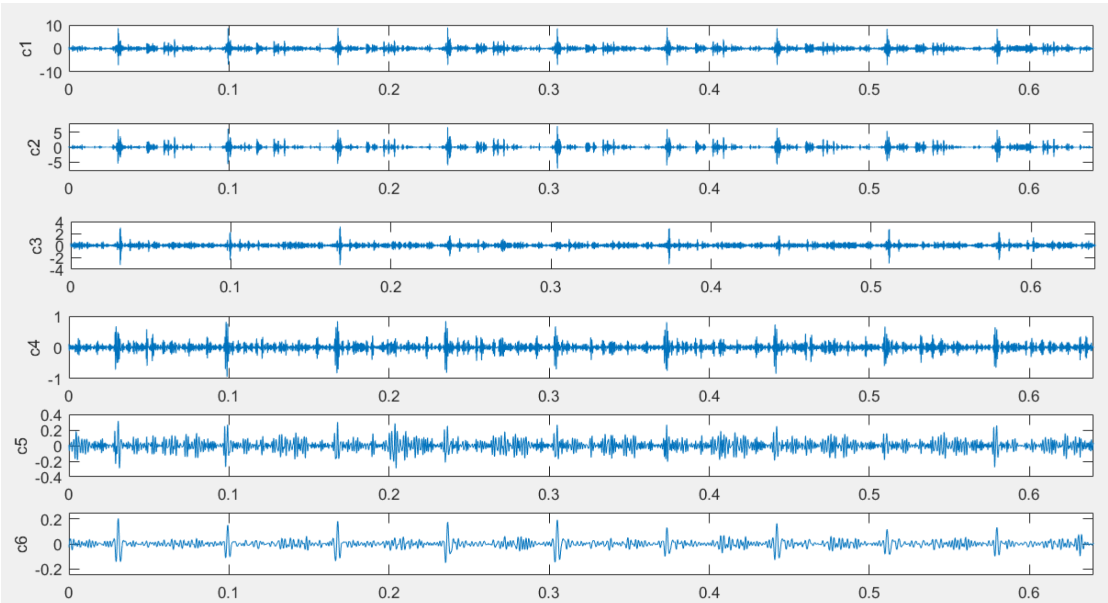

Figure 5. The first 6 orders of IMF component after piston pin failure is decomposed by EEMD

The AR spectrum of the first 6-order IMF component of the diesel engine vibration signal under the three operating conditions is shown in Fig. 6. The spectral line is smooth and the peak is easy to observe. In the IMF component of the same order of vibration signals in the middle condition, the peak positions are adjacent to each other and the center frequency of the band is almost the same. It can be seen from Fig. 7 that the power amplitude energy of the EEMD-AR spectrum is mainly concentrated within 7000 Hz. It can be seen from Fig. 6 that the characteristic frequency bands of the IMF1 in the piston wear failure, the piston pin wear failure and the normal working condition are 0~2700 Hz, 0~3150 Hz and 0~3500 Hz, respectively, which can clearly distinguish three kinds of operating conditions; the piston in IMF2 The characteristic frequency bands of wear failure, piston pin wear failure and normal working conditions are 0~2200Hz, 0~2500HZ and 0~3300Hz, and the incremental characteristic frequency range of piston pin wear fault is much wider than the other two working conditions, so it is very It is easy to diagnose the fault from the AR spectrum, and the AR spectrum attenuation is very slow in the frequency band of 2500~3400Hz under normal operating conditions, and then it will decay rapidly afterwards, and the AR spectrum of the piston wear fault is almost smoothly attenuated in the range of 2200~5000Hz. Therefore, the piston wear failure can be clearly diagnosed in this way, and the effect of extracting the characteristics of the 3 medium working conditions in the IMF2 is better than that of the IMF1. IMF3~IMF6 There is no significant difference in the AR spectrum of the three working conditions of the same order IMF, so feature extraction is not possible.

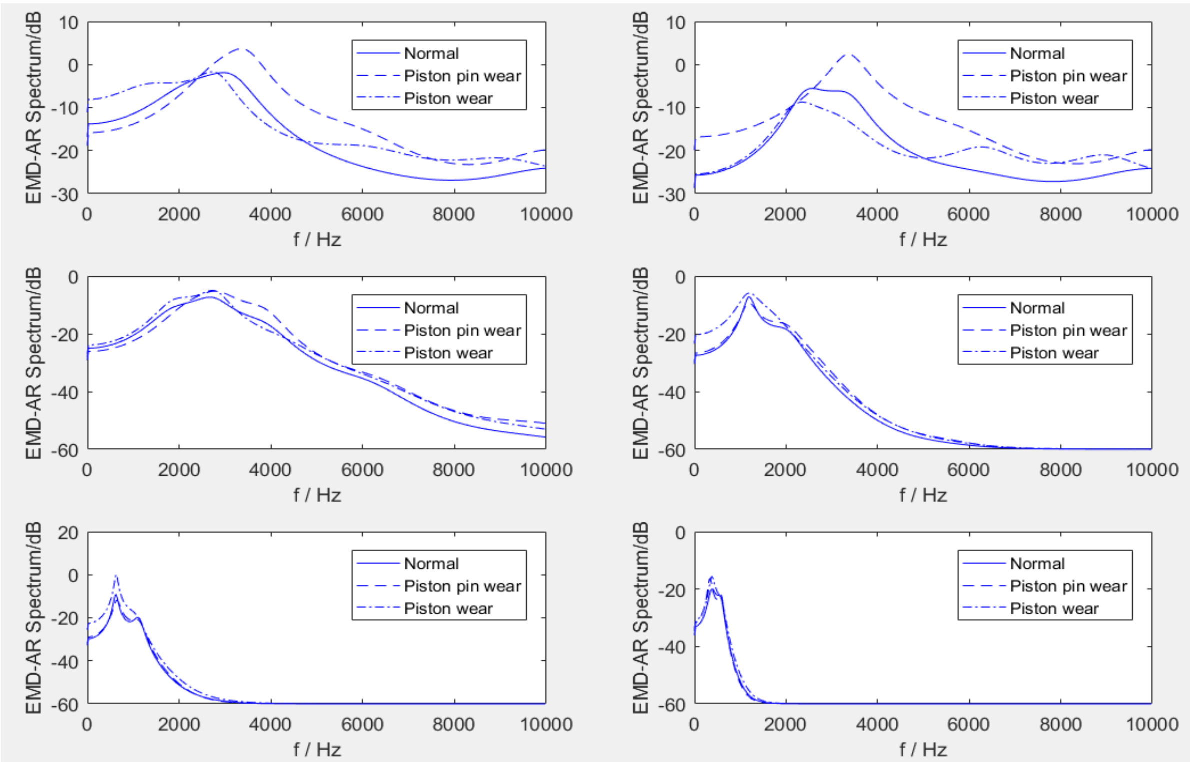

Figure 6. Comparison of AR spectra of the first 6-order IMF components of diesel engine vibration signals under three operating conditions

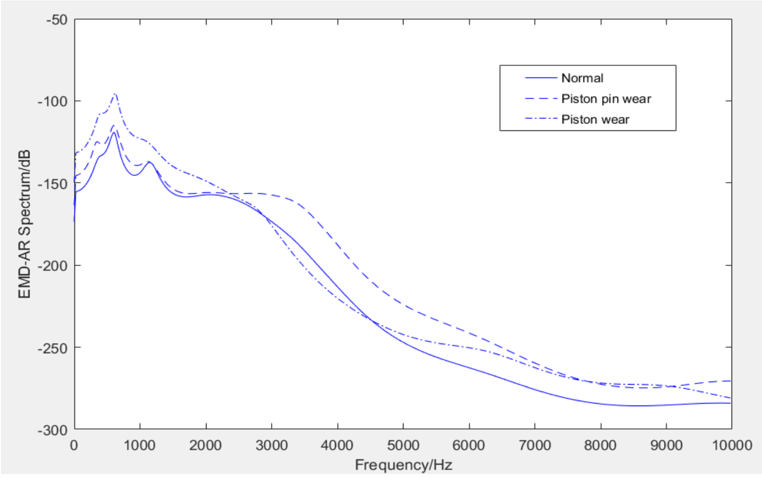

Figure 7. Comparison of the cumulative energy of the first 6 orders of IMF component AR spectrum under three operating conditions

5. Conclusion

1) EEMD has adaptive decomposition performance and is suitable for analysis of nonlinear and non-stationary vibration signals. A diagnosis method based on EEMD-AR is proposed. The diagnosis method is used to diagnose the piston and piston pin wear faults, and compared with the Fourier amplitude spectrum diagnosis method, the results are better than the Fourier amplitude spectrum diagnosis method.

2) The EEMD method is used to decompose the vibration signals of the diesel engine under three working conditions, and the first 6 orders of IMF components decomposed under the three conditions are analyzed by AR spectrum. The AR spectra of IMF1 and IMF2 can effectively extract the fault characteristics. Moreover, the fault characteristics of the IRF2 AR spectrum extraction are better. The experimental results show that the EEMD-AR method can effectively extract the fault characteristics of diesel engine piston and piston pin wear and improve the accuracy of fault diagnosis.

References

[1] Xiao Yunkui. Automobile Fault Diagnosis [M]. Beijing: Beijing Institute of Technology Press, 2006.

[2] Qi Fulei et al. Modern signal processing methods in mechanical fault diagnosis. Beijing: Science Press, 2009.

[3] Xia, Wang Xinqing, Xiao Yunkui, Liang Sheng.Application of EMD-AR spectrum to extract fault characteristics of diesel engine crankshaft bearings[J].Journal of Vibration,Measurement & Diagnosis,2010,30(03):318-321+342-343.

[4] Li Tianyun, Zhao Wei, Li Nan, Feng Guo, Gao Honghui. A New Method of Power Quality Detection Based on HHT[J]. Proceedings of the CSEE, 2005(17): 52-56.

[5] ZHANG Wei,WEN Fu-zhen,WANG Jian-jun,LIU Huan-lei.Analysis of nonlinear signal analysis using high-pass low-pass filtering and Hilbert-yellow transform[J].Journal of North China Electric Power University (Natural Science Edition),2013,40(02) :5-9.

[6] CHEN Ke,LI Ye,CHEN Wei.Application of EEMD Decomposition in Power System Fault Signal Detection[J].Computer Simulation,2010,27(03):263-266.

[7] ZHANG Xin,WU Yafeng,ZHU Shuaiqi. Bearing Fault Diagnosis Based on EEMD-HHT Marginal Spectrum[J].Science Technology and Engineering,2011,11(31):7625-7629.

[8] [8]Wang Zhijian, Han Zhennan, Liu Qiuzu, Ning Shaohui. Extraction of weak fault characteristics of rolling bearings based on MED-EEMD[J]. Transactions of the Chinese Society of Agricultural Engineering, 2014, 30(23): 70-78.

ISSN: 2664-9640

[9] YANG Wangcan, ZHANG Pei-lin, WANG Huai-guang, CHEN Yan-long, SUN Yi-zun. Gear Fault Diagnosis Based on EEMD Multi-Scale Fuzzy Entropy[J].Journal of Vibration and Shock,2015,34(14):163-167+187.

[10] Zhang Lingling, Xiao Jing, ed. MATLAB-based mechanical fault diagnosis technology case [M]. Beijing: Higher Education Press, 2016.11.

[11] Duan Lixiang, Zhang Laibin, Wang Zhaohui, Fan Jianchun.Diagnosis of Diesel Piston Cylinder Liner Wear Based on Characteristic Phase Segment[J].Lubrication Engineering,2006(03):44-46+58.