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LCD denoise and the vector mutual information method in the application of the gear fault diagnosis under different working conditions

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Abstract. In this paper, the full vector LCD method is proposed to solve the misjudgment problem caused by the change of the working condition. First , the signal from different working condition is decomposed by LCD, to obtain the Intrinsic Scale Component (ISC)whose instantaneous frequency with physical significance. Then，calculate of the cross correlation coefficient between ISC and the original signal, signal denoising based on the principle of mutual information minimum**.** At last**,** calculate the sum of absolute Vector mutual information of the sample under different working condition and the denoised ISC as the characteristics to classify by use of Support vector machine (SVM) .The wind turbines vibration platform gear box experiment proves that this method can identify fault characteristics under different working conditions. The advantage of this method is that it reduce dependence of man's subjective experience, identify fault directly from the original data of vibration signal. It will has high engineering value.

1. INTRODUCTION

Machinery vibration signal contains a lot of physical meaning information while high-profile fault information is often submerged in it. The key for fault diagnosis is how to extract the effective fault information and it is also an important topic of the fault diagnosis at present. Empirical mode decomposition (EMD) and resonance demodulation method is often used for fault diagnosis .But the further development of the EMD was seriously affect because of the endpoint effect and modal aliasing , and its is restricted due to the frequency of the IMF has no physical meaning which restrict the application in the project. Resonance demodulation method has a good theoretical basis, but how to select its pass filter parameters is often difficult. Although many scholars use various methods such as spectral kurtosis method to achieve a rational selection of optimal band pass, the actual use is greatly limited.

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Local characteristic-scale decomposition(LCD) is a new adaptive method for analyzing non-stationary signal and it developed in recent years. The basic idea of LCD is that: there is a sine curve which has a single modal and the partial matches between any maxima and adjacent minima, so the instantaneous frequency from LCD has physical significance. We can realize the mixed signal decomposition according to this approach to ensure that every ISC component contains a different vibration source information. Currently, LCD has been widely used in fault diagnosis of gears and bearings, Cheng Jun sheng[1] do the gear fault diagnosis in combination with LCD and envelope analysis ,the results showed that LCD method can be effectively applied to gear fault diagnosis, but he did not elaborate the reliability of the algorithm under different conditions . ZhengJingde[2] show that LCD has certain advantages over EMD, LMD and other methods in terms of the inhibition of the endpoint effect, the speed of calculation and the effect of decomposition by the experiment results.

Mutual information reflects the amount of information or statistical dependence of each other. The more correlation between two random variables, the greater the mutual information; otherwise, the smaller the mutual information.

Peng Suping [4] Implements the microseismic signal filtering and denoising by combined EMD and mutual information entropy. Usually, the fault signal and its ISC have high mutual information value, and therefore the value of the mutual information can be used as gear fault diagnosis features. The full vector theory is a method that uses the information fusion to carry out phase constant, amplitude of fusion of the signals in two directions, mainly to address the problem of shortage of single-channel information.

This paper puts forward a method to diagnosis gear fault under different working conditions by LCD combination with full vector mutual information. Comparing with the traditional method ,it have two advantages, on one hand, ensure the improvement of information, on the other hand, the fault feature can be obtained directly from the original vibration signal, without the subjective experience. Through analysis the full vector mutual information between samples and vibration signal of under different condition. The amplitude frequency modulation caused by different working conditions is reduced. Wind turbine gearbox vibration test proved this method can identify the fault characteristics under different conditions, it has a certain universality.

2. LCD and full mutual information vector feature extraction

Through the LCD decomposition and filtering Correlation coefficient ,we can obtained ISC signal containing vibration source information more. Calculation mutual information between sample and ISC signal as features for the classification. The steps of fault diagnosis method based on LCD and mutual information as follows:

(1)Provided n kinds of training sample under different conditions, referred to as $Class_1$, $Class_2$, ..., $Class_n$, using LCD algorithm decompose i-th training sample, and calculating the cross-correlation coefficient of ISC signal and the original sample, In cross-correlation maximum principle, select m ISC recorded as IS_i. A collection of total n ISC signal can be obtained by the above steps.

(2)Take the training sample of certain working conditions from the training sample set and denoted train1. Calculation mutual information of train 1 and Each ISC from IS1, sum absolute mutual information as Feature1 of train1; Calculation the followed mutual information and get N features, then consist of the eigenvectors of the sample train1 with n feature, again and again, compute feature vectors of all the training samples.

(3) using the training sample feature vectors train SVM classifier

(4) select test sample randomly, calculate the feature vectors in accordance with step (1), (2). Pattern recognition by using the trained SVM classifier and get the state of test.

3. Experimental verification

3.1. Data source

Based on the above method, the gear box fault of the wind turbine vibration platform produced by American SQi company is identified. The experiment platform mainly includes DT9837 signal acquisition system, 608A11 acceleration sensor,PHC-100 CLUTCH magnetic particle brake and Gear Fault Bench.

Gear Fault Bench consists of speed regulating motor, two stage gear transmission. The main parameters of the experiment are: the high-speed shaft driving wheel gear is 36, 90, low speed shaft driving wheel teeth is 29,100, the sampling frequency is 10000Hz, the sampling time is 1S.Wind turbine vibration test platform shown in Figure 1.

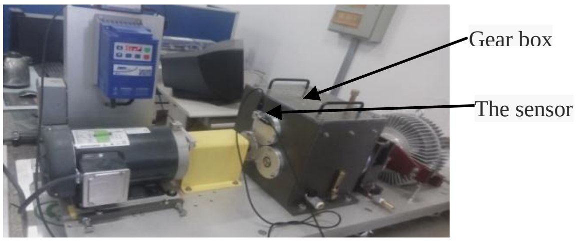
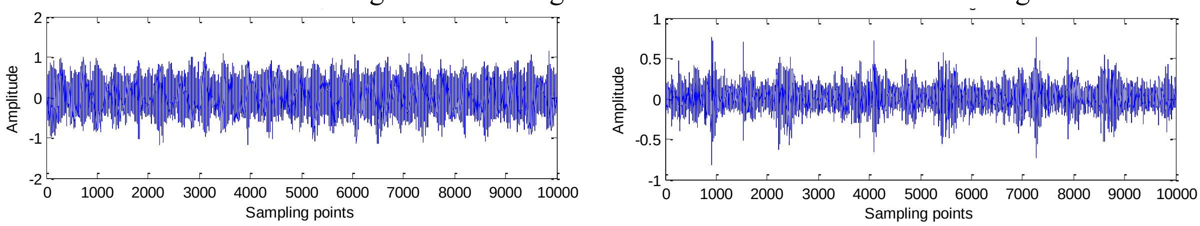


Fig.1 Wind turbines vibration experiment platform

3.2. RESULTS

The measured time domain signal of normal gear and tooth root crack is shown in Figure 2.



(a) Normal (b)Root crack

Fig.2 The time-domain signal of gear

In literature [7], the change of the load can cause the amplitude modulation phenomenon of the vibration signal, but no influence on frequency. While the change in the rotational speed caused FM phenomenon but no effect on the amplitude. LCD algorithm is mainly aimed at the frequency decomposition. Therefore, the condition of narrow load range(Load range 32 nm ~ 40 nm) and wide speed change(Speed range 180 r/min to 2000 r/min) are selected for experiment working. Randomly selected 50 groups of training sample and 100 groups of test sample.

The vibration signal of normal gear and gear of tooth crack under different working conditions is decomposed by LCD, The ISC components obtained are shown in Figure 3.

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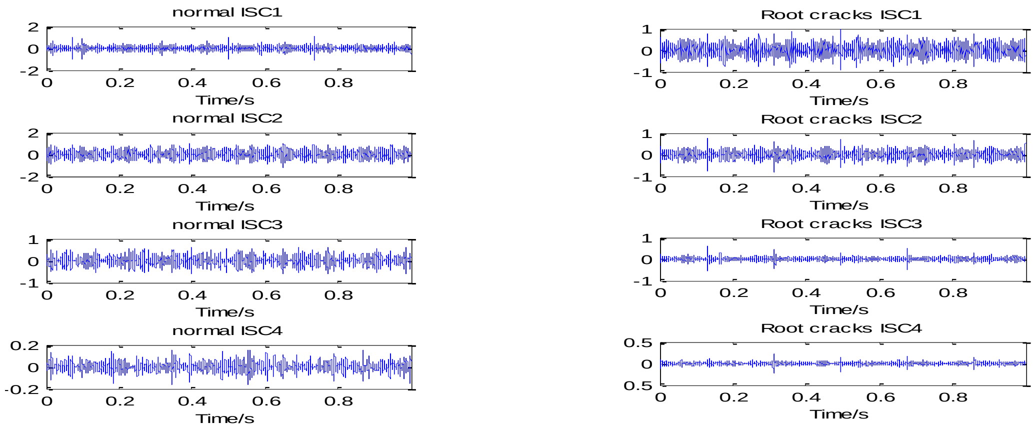

(a) Normal signal (b) Root cracks

Fig.3 ISC after signal decomposition

Compute the correlation coefficient of ISC and original signal ,the greater the coefficient, the more vibration signal component it contains. The correlation coefficient of ISC from normal/ tooth root crack and original signal are shown in table 1.

Tab.1 The correlation coefficient of the original signal and Normal/root crack

ISC	1	2	3	4	5	6
Normal	0.8937	0.2919	0.1112	0.0297	0.0605	0.0079
Root cracks	0.8893	0.3539	0.1410	0.0415	0.0110	0.0019

As shown in Table1, ,the correlation coefficient of the first 3 ISC components is greater than the mean value in all gear normal / root crack . That is to say, the first 3 ISC can fully express the signal characteristics. Through this method, on the one hand, noise reduction can be achieved, on the other hand the calculation of the total vector mutual information feature can reduced.

Record the filtered ISC of gear normal / root crack under n kinds of different conditions as Normal IS_n and Fault IS_n. The higher the N, the higher the coverage rate of the condition, and the greater accuracy of determination failure.

The gear normal / root crack information of vibration is used as the training sample, select s groups of signal from training samples denoted as $train_1$... $train_s$， and calculate mutual information with Normal IS_n and Fault IS_n. Part of full vector mutual information of are shown in Tables 2.

Tab.2 Sum of absolute full vector mutual information of the NIS_n/FIS_n and the R_s

	*NIS*1	*NIS*2	*NIS*3	*NIS*4	*NIS*5	*NIS*6	*FIS*1	*FIS*2	*FIS*3	*FIS*4	*FIS*5	*FIS*6
*NIS*1	0.4428	0.4545	0.2547	0.3574	0.3324	0.1368	0.0313	0.0492	0.0521	0.0521	0.0951	0.0657
*NIS*2	0.4204	0.5842	0.4478	0.3254	0.3124	0.3357	0.0863	0.0561	0.0656	0.0656	0.0811	0.0692
*NIS*3	0.4109	0.3562	0.2454	0.3241	0.4318	0.3349	0.0889	0.1821	0.1456	0.1456	0.0466	0.0721
*NIS*4	0.4014	0.3852	0.3612	0.3484	0.5231	0.2438	0.0693	0.0752	0.0851	0.0851	0.0812	0.0832
*NIS*5	0.4722	0.3484	0.3485	0.3241	0.3874	0.415	0.0385	0.0354	0.0645	0.0645	0.0684	0.0654
*FIS*1	0.0816	0.1024	0.0985	0.0657	0.0789	0.0763	0.2516	0.3452	0.3421	0.3241	0.3748	0.4325
*FIS*2	0.0808	0.0896	0.1245	0.0895	0.0854	0.1235	0.3688	0.3451	0.3631	0.2254	0.2894	0.4572
*FIS*3	0.0842	0.0778	0.0932	0.1024	0.0856	0.1034	0.3659	0.3841	0.3871	0.4621	0.3514	0.4327
*FIS*4	0.1153	0.1545	0.1679	0.1044	0.0867	0.1923	0.4829	0.3214	0.4324	0.5544	0.4512	0.4362
*FIS*5	0.1058	0.0864	0.0894	0.1865	0.0856	0.0942	0.5182	0.2842	0.3344	0.6854	0.5024	0.4216

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From the tables, the absolute full vector mutual information of root crack gear and Normal IS_n substantially larger than the value corresponding to the normal gear ,description root cracks and normal IS_n is complementary distribution. While, The absolute value of full vector mutual information of normal gear and Fault IS_n substantially greater than the value corresponding to the tooth root crack, description normal gear and Fault IS_n is complementary distribution .Therefore, sum of the absolute full vector mutual information as feature of normal signal and root crack signals can distinguish different states.

Sum of absolute full vector mutual information of training samples with Normal IS_n as Feature1,with Fault IS_n as Feature2. Establish distribution of features With Feature1and Feature2,it is shown in figure 4.

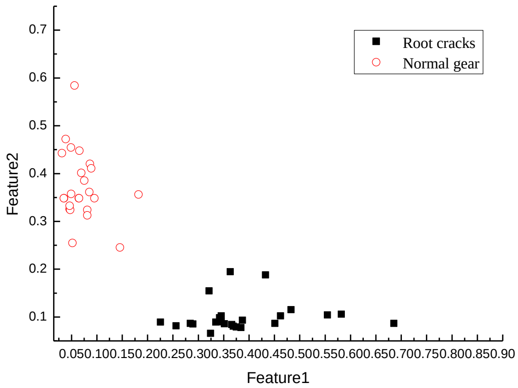

Fig.4 The characteristics distribution of the normal gears and tooth root crack

4. CONCLUSION

The following conclusions are obtained as follows:(1)The ISC contains some characteristic information of the weak fault of gear.(2) using the sum of absolute full vector mutual information as features, make up for the lack of single channel, at the same time , it avoid the impact of individual abnormal conditions. To compare with the direct mutual information ,its robustness and distinction extent are improved.(3)The method proposed in this paper can effectively extract fault feature of gear, and it does not depend on the subjective experience. It can solved gear fault diagnosis under different conditions.

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