WAVELET PACKET IMAGES MATCHING APPLIED TO NOISE FAULTS DIAGNOSIS

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Abstract: In order to avoid the difficulty of installing vibration sensors and extracting characteristic frequency vectors on the traditional vibration-based abrasion faults diagnosis of main bearing of diesel engine, this paper presents a new approach based on the noise signal of diesel engine and wavelet packet images processing. Based on that, the standard time-frequency distribution images of all fault conditions, including the gap abrasion information of main bearing, can be defined. Correspondingly, a gap abrasion fault diagnosis model of main bearing with images matching is set up. Through comparing the Euclid Distance values between standard fault images and the test image, the model can recognize the gap abrasion condition. The result shows that this method is simple and effective, and makes the best use of fault information.

Keyword: Fault Diagnosis, Gap Measurements, Images Processing, Images Matching, Noise, Time-Frequency

1. INTRODUCTION

Nowadays, there are many diesel engines used in chemical process industry. The fault diagnosis & monitoring of diesel engine is very difficult due to its complex structure. The main bearing is the important part of reciprocating engine, and its extreme abrasion can affect the normal operation of diesel engine. The gap measurements of main bearing are very significant. Faults diagnosis and conditions monitoring of most parts of a diesel engine (including piston, valve and so on) often base on the vibration signal. Vibration sensor is easy to approach those parts and sensitive to their abrasion faults. But the main bearing locates in the interior of diesel engine, so diesel engine has to be disassembled for installing a vibration sensor near main bearing; but it will result in a lot of troubles. If using noise measurements in the exterior of diesel engine to realize the faults diagnosis and monitoring of main bearing, it will bring very important meanings. In addition, the variety of gap condition of main bearing does not cause the obvious variety of vibration & noise signals; the work processing of diesel engine is a non-stationary shock processing, its energy has a wide distribution in frequency domain, and from the ordinary spectrum figure, it is very difficult to find its fault characteristics similar to those of rotating machinery. In references (Liu Shiyuan, et al., 1999; Geng Zhongxing, Qu Liangsheng, 1994; Xu Min, 1998), wavelet packet and wavelet analysis are used to extract signal characteristics from time domain and some special frequency domain of vibration signal, and these methods all have a satisfactory result. However, all above methods does not make the best use of time-frequency information included in vibration signal; in addition, those methods are based on vibration signal, and not use the noise-based approach that is more easier and effective for fault monitoring of main bearing. Based on that, this paper presents a new fault diagnosis method based on wavelet packet images processing and noise signal.

2.EXPERIMENT AND EXPERIMENT CONDITION

In order to research the relationship between noise signals and the gap abrasion conditions of main bearing, the test equipment is set up specially, as shown in Fig.1. This test diesel engine is a 2100 diesel engine, connected with a waterpower loadometer that can adjust the output power. A ND2 acoustic detector is used to sample the noise signals of diesel, the capacitor microphone of it should be located on the same horizontal level with the main bearing of diesel, so its distance to the engine is 0.8m, its height to the ground is 0.75m. The noise of diesel is usually relatively stronger in some directions and weaker in other directions. So the first step is to scan the surface of diesel for a best measuring position, which can assure the best radiation direction of sound energy, see (Xu Min, 1998; Lu Chen, 2002).

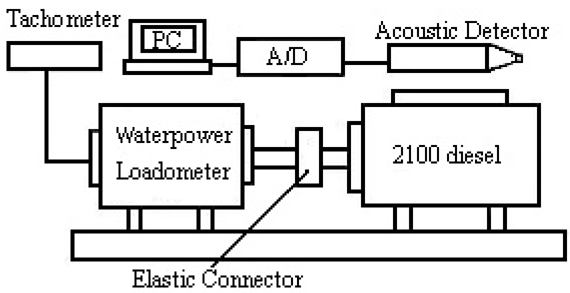


Fig.1. Sketch map of test equipment

In order to obtain measurement result exactly, it is necessary to simulate four conditions of gap abrasion of the main bearing (0.12mm, 0.20mm, 0.26mm, 0.30mm). The limited maximum gap abrasion of the test main bearing is 0.25mm, so the above four conditions of testing gap include basically all work conditions from normal gap to serious abrasion. In addition, rotating speed: 1200r/min, output power: 80%, sample rate: 10.8KHz, sample length: 8192 points.

In order to obtain a highest precision, it is also necessary to mark the noise signal sample. Firstly, need to measure the pressure signal in the interior of cylinder by installing a pulse sensor near the camshaft. The angle range is from -360° to 360° during a work cycle of diesel. During the course of test, record each maximum pressure value while breaking off oils and regard it as 0°. Through the above method, it can be assured that the length of noise signal is integral multiple of a work cycle of diesel.

3.WAVELET ANALYSIS OF NOISE SIGNAL

In our previous research, wavelet analysis was applied to the fault diagnosis of gap abrasion. This method uses wavelet analysis to extract the high frequency band of noise signal, and then uses Hilbert transform to extract the envelope of the high frequency band. Finally, FFT spectrum of the envelope can be obtained. As a result, it is found that the amplitude values of 0.5× rotating speed and 2× rotating speed frequency are very sensitive to gap abrasion of main bearing, and increase along with the increment of gap abrasion, see (Lu Chen, 2002).

Wavelet analysis can judge the gap abrasion conditions of main bearing, but it does not make the best of the information included in noise signals. Wavelet packet analysis has no redundant results and does not damage the any information of signal. It can also process a detailed decomposition for both low frequency band and high frequency band. Therefore, it is very fit for the analysis of non-stationary random signal, like the vibration & noise signal of diesel engine.

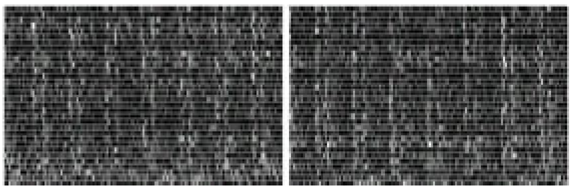
4. WAVELET PACKET ANALYSIS OF NOISE SIGNAL AND IMAGES PROCESSING

4.1 The Principle Of Wavelet Packet

The basic idea of wavelet analysis is to use a cluster of wavelet functions to express a signal. It has a high time-frequency resolution in low frequency bands, a high time resolution and low frequency resolution in high frequency bands. The main information of discrete wavelet transform locates in low frequency domain. The above characteristic is just the shortcomings of discrete orthogonal wavelet. However, the theory of wavelet packet imports a best-basis rule on the base of wavelet theory. It can reflect the characteristic of signal more effectively, and process a more detailed decomposition for high frequency bands. As a result, the decomposition sequence has a high time-frequency resolution and same bandwidth in the whole time-frequency domain. Due to the limit of pages, more detailed theory about wavelet packet, please see the relevant reference, see (Hu Changhua, and Zhang Junbo, 1999; Mallat S.A, 1989; Coifman R.R and Wickerhauser M V., 1992; Geng Zhongxing, Qu Liangsheng, 1994).

4.2 Time-Frequency Phase Plane Express Of Noise Signal And Images Processing

Phase plane is a two-dimension plane composed by time axis and frequency axis. It is not a function relationship, but a state expression and a real expression of signal. If sample length of signal is N, then the result of wavelet decomposition can be expressed by N adjacent rectangles (the area of each rectangle is $\Delta t \times \Delta f$). Δt and Δf represent the resolution of time axis and frequency axis respectively. The different gray color value in each rectangle just represents the amplitude value. So the time-frequency characteristics of signal can be clearly expressed on time-frequency phase plane. The different gap conditions of main bearing will lead to the change of time-frequency distribution of noise signal, see (Geng Zhongxing and Qu Liangsheng, 1994).



(a) (b)

Fig.2 Time-frequency distribution images of two gap conditions (a: 0.30mm; b: 0.20mm)

The gray values of image can be decided by the following method: firstly, normalize each level of coefficients after wavelet packet decomposition; then get corresponding gray values from these coefficients multiplied by 255, and the level length of decomposition is 5. Through our analysis, it can be found that each different gap of main bearing corresponds to one different time-frequency distribution figure. Even the time-frequency distribution figures of noise signals under the same gap condition from different starting time of sample are also little different from each other. It shows that the wavy behavior always exists in different work cycles of diesel; in other words, time domain noise waveforms of different work cycles are little different from each other. Simultaneously, on the time-frequency distribution images of different work cycles under the same gap condition, the gray values of some pixels at those corresponding frequency bands are also different from each other. Therefore, the time-frequency distribution image can include all information reflecting the work condition of diesel and give the extent of amplitude value of any time point and frequency band. In order to restrain the disturbance of noise and stand out fault characteristics, the method of images average processing is presented in this paper. It is consistent with the method of parameters average.

The image is formed by software method: firstly, processing wavelet packet decomposition for noise signal, then its time-frequency distribution image will be displayed on computer screen. Through programming, the position coordinates and gray values of all pixel points can be obtained, then save these data as an image file format. Finally, the time-frequency distribution images under different gap conditions can also be obtained. In our experiment, the size of image is 481×386, the range of gray value is 0~255. Certainly, the wider range of gray value can enhance the resolution of image, and reflect more details of wavelet packet decomposition.

5. FAULT DIAGNOSIS MODEL OF INTERNAL COMBUSTION ENGINE BASED ON IMAGES MATCHING

5.1 Images Average Processing

From the above discussion, it is known that, there exists wavy phenomenon among different work cycles of diesel, and also in the interior of each work cycle, so the differences of time-frequency distribution of different cycles under the same work and gap condition should not be neglected. If only use one single noise signal sample as the base of the abrasion fault diagnosis of main bearing, it will lack of correctness. Therefore, it is necessary to process an average for all time-frequency distribution images of one work and gap condition, so as to lessen the wavy effect and stand out the fault information. In our experiment, select respectively 10 time-frequency distribution images to average for 4 types of gap conditions of main bearing, then get four "standard" images representing 4 types of gap conditions. In order to verify the validity, it needs to use 10 images to average for obtaining "standard" images, and five images to average for processing fault diagnosis of main bearing, see (Cheng Guiming and Zhang Mingzhao, 2000). Certainly, the number of images to be averaged can also be larger than 10 or 5. Moreover, the larger number can improve the precision of fault diagnosis.

If, an images cluster $A_k(i,j)$,k=0,1,2,…N. The gray value of the (i, j) pixel unit in $A_k(i,j)$ is $G_k(i,j)$. (i is row, j is column), then after the average processing, the gray value of the (i, j) pixel unit in the standard image (averaged) of any gap condition of main bearing is below:

$$SG_m(i,j) = \frac{1}{N}\sum_{k=1}^{k=N} G_k(i,j) \quad (1)$$

In equation (1): m=1,2,3,4; i=1,2,…,N_L, j=1, 2,…,N_S; N_L is the row count of image pixels. N_S is the column count of image pixels. Let N in equation (1) be 10 as computing each "standard image", and be 5 as processing fault diagnosis (computing "test image"). The Euclid Distance between two images is defined as equation (2).

In equation (2): $N=N_L \times N_S$, it is just the total count of image pixels; A(i,j) is the gray value of the (i, j) pixel in test image, $SG_m(i,j)$ is the gray value of the (i, j) pixel in m-th "standard image". The length of noise signal used to produce each standard/test image is integral multiple of a work cycle of diesel. Certainly, for any gap condition, 10 noise signal samples of standard image are all from the same time series, and the same to 5 noise signal samples of test image.

$$D_m = \sqrt{\frac{1}{M}\sum_{i=1}^{i=N_L}\sum_{j=1}^{j=N_S}[A(i,j) - SG_m(i,j)]^2}$$

m=1,2,3,4 (2)

5.2 The Decision Of Threshold Value

During the process of fault diagnosis, for any image A(i,j) (test image) after the average of 5 images, according to equation (2), compute each Euclid Distance value D_m between four “standard” images and test image (m=1,2,3,4). $D_{min}=\min\{D_m\}$, define the difference between any one of four Euclid Distance values and D_{min} as below:

$$C_m=|D_m - D_{min}| \quad (3)$$

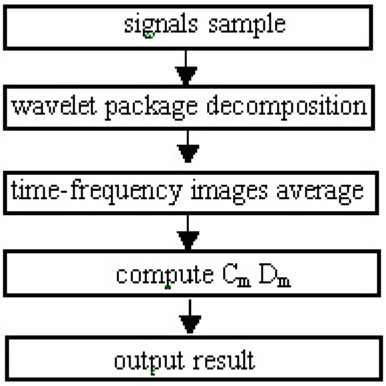


Fig.3 Process of diagnosis

Through test analysis, a diagnosis threshold value can be set V_d=5. For any test image, if there is only one $C_m<V_d$, then the gap abrasion condition of main bearing is just the one which this C_m corresponds to. Whereas, if there are more than one $C_m<V_d$, then it is no way to judge.

6. DIAGNOSTIC EXAMPLE

In Fig.4, each on the left side is the standard image, which represents one of four gap conditions of main bearing, and the right ones are test images. From top to bottom, it is 0.12mm, 0.20mm, 0.26mm and 0.30mm respectively.

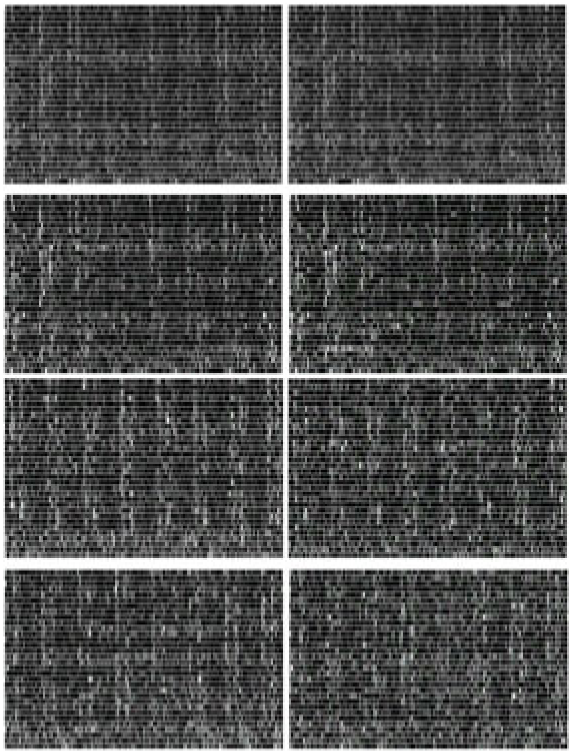


Fig.4 Standard images and test images

In Fig.4, it shows that, there are differences among the four “standard” images. Simultaneously, each “standard” image is quite similar to its corresponding diagnosed image under the same gap condition; it is because the processing of images average can extract the characteristics of images and restrain the noises. According to the steps shown in Fig.3, for each gap condition, selecting two averaged images to diagnose. The result is shown in Table 1.

In Tab.1, SI represents standard image, S1~S8 are test images, D1~D4 are the Euclid Distance values between the standard images and the test images, R represents result, and Gap1~Gap4 represent the diagnostic results of gap conditions.

In our experiment, 30 test images are analyzed by the above method in our experiment, only one image can be not classified, and all the others can be classified correctly. The rate of recognition can reach to 95%.

Tab.1 Euclid distance between standard images and test images

	SI D1	SI D2	SI D3	SI D4	R
S1	15.3	65.7	56.7	52.1	Gap1
S2	63.6	29.3	66.1	58.7	Gap2
S3	57.4	69.3	27.7	62.5	Gap3
S4	54.1	62.3	61.7	16.5	Gap4
S5	17.2	67.9	58.1	53.3	Gap1
S6	60.4	26.1	63.8	56.7	Gap2
S7	55.5	67.5	25.5	57.4	Gap3
S8	53.9	61.6	63.2	17.6	Gap4

7.CONCLUSIONS

From Tab.1, a conclusion can be deduced that, if using images matching model based on Euclid Distance to diagnose the gap condition, then the differences of D_m between the test image sample and each of "standard" images are very distinguished. The essence of this method is, on the time-frequency phase plane, the similar extent of positions and amplitude values of all frequency bands is expressed by Euclid Distance between two time-frequency images. The average method can be used to reduce the wavy effect and noise disturbance, but not solve this problem radically. Certainly, the number of images to be averaged can also affect D_m.

Through wavelet packet analysis, the detailed information of each time domain and frequency band can be obtained. The noise signal of diesel has the characteristic of non-stationary and includes abundant condition information of diesel, so wavelet packet is suitable for analyzing it. Through the test result, it shows that the abrasion fault diagnosis model based on images matching has a strong practicability and feasibility, and the noise signal based method is also feasible. In addition, the threshold value is mainly decided by experience, so far, there is not a quantitive analysis method, it need to be improved in future research.

8.ACKNOWLEDGEMENT

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