ELSEVIER
Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia Engineering 15 (2011) 2454 – 2458
Procedia Engineering
www.elsevier.com/locate/procedia

Advanced in Control Engineering and Information Science

Research on Fault Diagnosis of Diesel Engine Based on Bispectrum Analysis and Genetic Neural Network

Fuzhou Feng[a], Aiwei Si[b], Hongxing Zhang[c], a*

[a, b]*Department of Mechanical Engineering, Academy of Armored Force Engineering, 21Dujiakan District, Beijing 100072, China*
[c]*Taiyuan Satellite Launch Center, No.6 of 41 postbox, Kelan 036304, China*

Abstract

Aimed at the problem of the feature of nonstationary vibration signal can not be extracted easily; the bispectrum analysis technique was researched in this paper. Bispectral characteristic frequency faces were searched along the parallel to the diagonal line at certain step in the bispectral modulus field, and the mean magnitude was calculated to get the feature parameters. The method was applied in fault feature extraction of piston-pin of diesel engine successfully. Finally, the piston-pin faults were diagnosed associated with genetic neural network.

Selection and/or peer-review under responsibility of [CEIS 2011]

Keyworks: bispectrum; genetic neural network; diesel engine

1. Introduction

Because of the combined shock raised by multi-mechanism motion, the vibration signal of diesel engine is nonlinear and nonstationary in strict meaning on the condition of diesel engine running steadily. Therefore, the vibration feature of diesel engine components can not be reflected by time-domain waveform and spectrum analysis preferably. The vibration signal of piston-pin is produced by the shock of piston-pin to piston-hole or small hole of connecting rod. The main reason of abnormal sound or vibration being too acute is abnormal gap induced by wear [1]. The vibration signal of piston-pin is influenced by impact caused by other components inescapably, and the amplitude is increasing along with the rotate

* Corresponding author. Tel.: +86-10-66719253; fax: +86-10-66719253.
E-mail address: fengfuzhou@tsinghua.org.cn.

1877-7058 © 2011 Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
doi:10.1016/j.proeng.2011.08.461

speed being rising, which belongs to nonstationary signal. But the vibration signal of engine has periodicity, the natural frequency of each component is invariable, when the sampling frequency is high, the vibration signal of piston-pin can be regard as a sort of cyclic stationary signal [2].

Bispectral is a high-order cyclic cumulant, which can separate stationary signal and cyclostationary signal availably, and can completely control any stationary or nonstationary colored gaussian noise. At the same time, bispectral can distinguish the time-varying phase information and characterize nonlinear signal, which has been applied in the area of mechanical fault diagnosis and vibration analysis [3].

In this paper, bispectral technique was applied in analyzing the vibration signal of piston-pin on the different conditions, and the bispectral feature frequency face was gained, which was regarded as feature parameters and enter them into neural network to do the pattern recognition, the diagnosis effect is preferable.

2. Bispectrum Calculation

2.1. Define of Bispectrum

For cyclostationary process $x(t)$, order $X(w)=\sum_{t=0}^{T-1} x(t)e^{-jwt}$, which denotes the finite Fourier transform of $x(t)$, the bispectrum define of the process can be described as Eq.(1) [4]:

$$B_x(w_1,w_2)=E[X(w_1)X(w_2)X^*(w_1+w_2)] \tag{1}$$

2.2. Calculation of Bispectrum

There are two methods to do bispectrum estimation, including nonparametric model and parametric model, and each model includes direct method and indirect method. In this paper, the direct method of nonparametric model estimation is adopted, whose computational cost is less than indirect method.

Hypothesize the length of observation sequence $\{x(t)\}(i=1,2,...,N)$ is N, and the sampling frequency of which is f_s. In the bispectrum-domain, the frequency sampling number of w_1 and w_2 is N_0, thus, the frequency sampling interval is $\Delta_0 = f_s / N_0$. The calculational step of this method is as follows:

1) The length of data is N, order the number of subsection as k, each subsection includes M observation samples, and permit each subsection data to superpose. Then, subtract the mean of each subsection data.

2) Do the DFT transform to the j th subsection data:

$$\hat{X}^j(\lambda)=\frac{1}{M}\sum_{i=1}^{M} x^j(i)\exp(-j\frac{2\pi}{M}i\lambda) \tag{2}$$

3) Based on the coefficients of DFT, calculate the bispectrum estimation of each subsection data:

$$\hat{B}_x^j(\lambda_1,\lambda_2)=\frac{1}{\Delta_0^2}\sum_{k_1=-L_1}^{L_1}\sum_{k_2=-L_1}^{L_1}\hat{X}^j(\lambda_1+k_1)\hat{X}^j(\lambda_2+k_2) \hat{X}^j(\lambda_1+k_1+\lambda_2+k_2) \tag{3}$$

4) Statistical average the bispectrum estimation results of each subsection data:

$$\hat{B}_x(w_1,w_2)=\frac{1}{k}\sum_{j=1}^{k}\hat{B}_x^j(w_1,w_2) \tag{4}$$

In the Eq.(4), $w_1 = \left(\frac{2\pi f_s}{N_0}\lambda_1\right)$, $w_2 = \left(\frac{2\pi f_s}{N_0}\lambda_2\right)$.

The value of bispectrum estimation is complex number, do the modular operations to the bispectrum-domain, and consider the symmetry of bispectrum, the 12 symmetrical intervals can be gained:

$$\begin{aligned} |B_x(w_1,w_2)| &= |B_x(w_2,w_1)| = |B_x(-w_2,-w_1)| \\ &= |B_x(-w_1,-w_2)| = |B_x(-w_1-w_2,w_2)| \\ &= |B_x(w_1,-w_1-w_2)| = |B_x(-w_1-w_2,w_1)| \\ &= |B_x(w_2,-w_1-w_2)| = |B_x(-w_2,w_1+w_2)| \\ &= |B_x(w_1+w_2,-w_2)| = |B_x(-w_1,w_1+w_2)| \\ &= |B_x(w_1+w_2,-w_1)| \end{aligned} \quad (5)$$

The position of each interval is shown in Fig. 1.

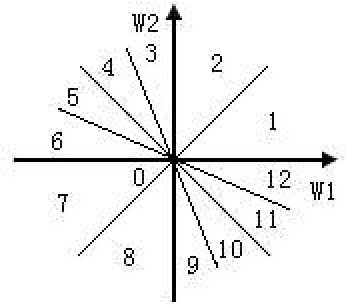


Fig. 1 The symmetrical intervals in the field of bispectrum modulus

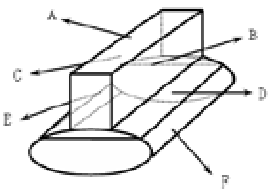
In Fig.1, the amplitude symmetry axis in interval 1, 2, 7 and 8 is $W_2 = W_1$; the amplitude symmetry axis in interval 3, 4, 9 and 10 is $W_1 = -W_2/2$; and the amplitude symmetry axis in interval 5, 6, 11 and 12 is $W_2 = -W_1/2$. Thus, we only have to analyze amplitude in some intervals.

3. Vibration Signal Acquisition of Piston-pin

The diagnosis object is the mechanical power train of a Cummins 6BT diesel engine installed in an automobile of Dongfeng EQ2102, the engine has a turbocharger and 6 cylinders inline, and the rated power is 85kw. In the experiments, three conditions were set as Table 1. The locations of the vibration sensors are shown as Fig. 2.

Table 1. Fault parameter setting

Condition	Design condition	Fit clearance of piston-pin
Condition F_1	Normal condition	0.01mm
Condition F_2	Fit clearance is big	0.10mm
Condition F_3	Fit clearance is too big	0.20mm



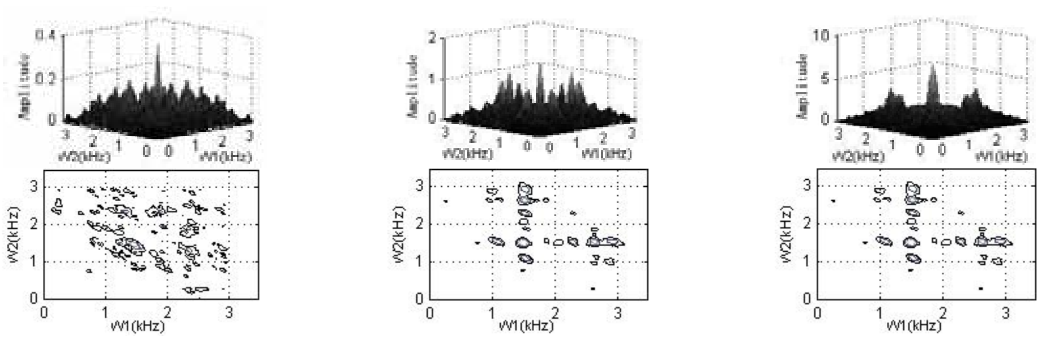
A. Top of the third cylinder; B. Right upside of the third cylinder; C. Left upside of the third cylinder; D. Right connection parts between cylinder body and oil pan of the third cylinder; E. Left connection parts between cylinder body and oil pan of the third cylinder; F. Oil pan

Fig. 2 Locations of accelerative vibration sensors

The preset value of the starting rotary speeds for the nonstationary data acquisition system is 800r/min, 1300 r/min, 1800 r/min and 2100 r/min respectively while the engine is operating in acceleration process. The sample frequency is 25600 Hz, the sample number are 4096.

4. Bispectrum Analysis

The length of data is $N = 4096$, order each subsection observation samples $M = 1024$, the superpose degree of each subsection data is 50%, and the number of subsection is $K = 2 * N / M - 1 = 7$. When the rotary speed is 1800 r/min, calculate the bispectrum of vibration signal in Location D of the third cylinder on the three conditions. The amplitudes and contours are shown in Fig. 3.



(a) Fit clearance is 0.01mm (b) Fit clearance is 0.10mm (c) Fit clearance is 0.20mm

Fig. 3 The bispectrum modulu amplitudes and contours in Location D of the third cylinder on the three conditions

From Figure 3, we can see that the valid frequency focus within 3500Hz, the contours on different conditions have large difference. Following the increasing of fit clearance, the peak value of feature frequency is more and more obvious. In order to seek the fault features, search and compare the amplitudes in interval 1.

In this paper, the method for searching feature face is searching along the parallel beelines which parallel with diagonal; the length of changing step is 25Hz.

Compare the vibration signal acquired in 4 kind of rotary speeds on 6 locations, the signal in 1800r/min on location D and E is preferable. Search the feature face to the signal, and arrange descend the feature face according to the patency degree.

5. Fault Diagnosis

Based on the feature face positions shown in Fig. 4, calculate the average amplitudes in feature face as the training samples. The neural network applied in this paper is genetic neural network [5]. The number of nodes in input layer is 10, the number of nodes in output layer is 3, and the number of the nodes in middle layer is 15. Order the number of population as 30, after 2020 learning, the output error of neural network is less than 0.005, which satisfies needs.

Check the trained neural network by the checking samples acquired by the same condition for getting the training samples, the checking samples and the outputs of neural network are shown in Table 2. Comparing the anticipant outputs and actual outputs of neural network, we can see that the GA-BP neural network could diagnose the faults successfully, which proves that the feature parameters can reflect the character of vibration signal of piston-pin preferably.

Table 2. The checking samples and outputs of GA-BP neural network

No.	Inputs of neural network										Anticipant outputs			Actual outputs		
1	0.051	0.051	0.048	0.083	0.033	0.044	0.056	0.035	0.032	0.039	1	0	0	0.99965	0.00534	0.00006
2	0.043	0.026	0.036	0.050	0.016	0.050	0.026	0.050	0.024	0.049	1	0	0	0.99983	0.00388	0.00004
3	0.052	0.031	0.060	0.088	0.025	0.043	0.037	0.051	0.038	0.062	1	0	0	0.99967	0.00514	0.00006
4	0.762	0.559	0.977	0.432	0.421	0.201	0.340	0.082	0.128	0.209	0	1	0	0.00477	0.80461	0.33710
5	0.526	0.598	0.659	0.342	0.370	0.108	0.320	0.057	0.187	0.143	0	1	0	0.01186	0.88184	0.07747
6	0.179	0.544	0.332	0.217	0.097	0.117	0.239	0.071	0.138	0.146	0	1	0	0.16952	0.73639	0.00756
7	1.431	1.707	1.292	1.522	1.098	0.909	1.163	0.348	0.479	1.326	0	0	1	0.00075	0.00139	0.98364
8	1.486	2.227	1.283	1.697	1.132	0.540	1.215	0.287	0.774	1.243	0	0	1	0.00021	0.01365	0.99317
9	1.604	1.849	1.807	1.660	1.115	0.605	1.009	0.286	0.532	1.496	0	0	1	0.00006	0.00934	0.99556

6. Conclusions

1) The optimal diagnosis positions is the right and left connection parts between cylinder body and oil pan, the optimal diagnosis rotary speed is 1800r/min, and the feature frequency is 1300Hz-3000Hz;

2) The signal features of bispectrum analysis not only exist on the diagonal, but also exist on other area.

3) The signal features can be described preferably by the feature face, and the effect of inputting the feature parameters gained from feature face into the GA-BP neural network to do fault diagnosis is good.

Acknowledgements

The work is supported by the National Natural Science Foundation of China (Grant No. 51075396).

References

[1] Bai X, Huang B, Wang L C. Study on Virtual-Prototype-Based Failure Diagnosis of Engine Piston Pin [J]. Automobile Technology, 2005, no. 4, pp. 20-23.

[2] Xiao Y K. The Automobile Fault Diagnosis [M]. Beijing: Beijing Institute of Technology Press, 2006.

[3] Zhang X D, Bao Z. Analysis and Processing of Nonstationary Signal [M]. Beijing: National Defence Industry Press, 1998.

[4] Yang D M, Stronach A F, MacConnell P, etal. Third-order spectral techniques for the diagnosis of motor bearing condition using artificial neural networks [J]. Mechanical Systems & Signal Processing. 2002, vol. 16, no. 2-3, pp. 391-411.

[5] Feng H S, Fu Y, Jiang G P, etal. Application of the Improved Genetic Neural Network Method to Vehicle Fault Diagnosis [J]. Journal of Academy of Military Transportation, 2006, vol. 8, no. 1, pp. 54-57.