The Open Automation and Control Systems Journal

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The Open Automation and Control Systems Journal, Volume 7, 2015

ISSN: 1874-4443/15
DOI: 10.2174/1874444320150610E001

Article Type: Review Article

Received: January 16, 2015
Revised: March 23, 2015
Accepted: May 31, 2015

Provisional PDF Publication Date: June 16, 2015

The Diaphragm Pump Spindle Fault Diagnosis using HHT Based on EMD

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Abstract: The running performance of reciprocating piston diaphragm pump spindle affects reciprocating diaphragm pump operating conditions directly, even the effective operation of the entire pipeline transportation systems. Because of the diversity and uncertainty of the diaphragm pump spindle fault, this paper proposes a fault diagnosis method of HHT based on EMD. Firstly it can process the original signal vibration data by EMD to get some IMF, then analyze each IMF through Hilbert transform to get HHT marginal spectrum, finally study the HHT marginal spectrum of IMF to achieve equipment fault diagnosis and research. The experimental results show that the method of HHT based on EMD is effectively and feasibly for fault diagnosis of reciprocating piston diaphragm pump spindle.

Keywords: Reciprocating piston diaphragm pump, Spindle, EMD, HHT, Marginal spectrum, Failure diagnosis.

1. INTRODUCTION

With the continuous development of pipeline technology, the pipeline transport is not only bringing considerable economic value, but also changing the way people live. Reciprocating piston diaphragm pump which is the power output device pipeline is one of the core equipment of pipeline system, so the security issue reciprocating piston diaphragm pump is the key issue of pipeline transport. But the spindle is one of the most important parts of a reciprocating piston diaphragm pump. In the process of diaphragm pump operation, the spindle failure is most deadly, once spindle appears fault, it will cause huge economic losses, and even casualties. Therefore, the fault diagnosis of reciprocating diaphragm pump spindle is importantly and valuably.

Due to the failures of the reciprocating piston diaphragm pump is diversity, uncertainty and concurrency[1,2], fault diagnosis of diaphragm spindle is very difficult. This paper presents a method of HHT based on EMD for reciprocating piston diaphragm pump spindle fault diagnosis. Firstly it can process original vibration signal by empirical mode decomposition EMD to get a limited number of intrinsic mode function IMF; then analyze each IMF through Hilbert transform to get HHT marginal spectrum; finally study the HHT marginal spectrum of IMF. So that it can reflect accurately the failure frequency characteristic of reciprocating piston diaphragm pump spindle through analyzing the strong changed fault characteristics of IMF marginal spectrum.

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2. RECIPROCATING DIAPHRAGM AND SPINDLE INTRODUCTION

Reciprocating piston diaphragm pump is mainly composed of motor, crankshaft, connecting rod, slider, spindle and piston and so on. It generates power by motor to drive crankshaft in a circular motion, then the connecting rod drives spindle reciprocating movement together, so the spindle transmits power to piston to squeeze the oil medium. So that it produces difference liquid pressure by the oil medium and completes the slurry transportation[3].

3. EMD AND HHT

HHT (Hilbert-Huang Transform) has prepared and adaptation for non-linear signal or non-stationary signal. The complex signal can be decomposed into a finite number of intrinsic mode function IMF by EMD. It uses Hilbert transform to solve the instantaneous frequency and instantaneous amplitude on each IMF, and then it obtains Hilbert spectrum and marginal spectrum of the signal, so achieve fault diagnostic analysis [4].

3.1 EMD

The EMD method is a process that IMF can be separated from complex signal. The instantaneous frequency of complex signal after Hilbert transformed has a physical meaning [5, 6]. EMD decomposition process is summarized below:

(1) Determine all local extreme point of the signal $x(t)$

(2) Connect all the local maximum points and minimum points respectively, so that formation of one upper envelope and one lower envelope.

(3) Denote the average of the upper envelope and lower envelope as $m(t)$, is given by:

$$c(t) = x(t) - m(t) \tag{1}$$

Check, if $c(t)$ is a IMF, then $c(t)$ is the first IMF of $x(t)$, so a residual function can be obtained through separating $c(t)$ from $x(t)$.

$$r(t) = x(t) - c(t) \tag{2}$$

Otherwise, the $c(t)$ as original data, repeating steps (1) ~ (3).

(4) Repeat steps (1) ~ (3), until $r(t)$ becomes a monotonic function that can't extract any IMF, the cycle ends. Complete the EMD decomposition.

In this way, the original signal can be expressed as the sum of a residual function and some IMFs:

$$x(t) = \sum_{i=1}^{n} c_i(t) + r_n(t) \tag{3}$$

3.2 HHT and Marginal Spectrum

Hilbert transforms the IMFs to calculate the instantaneous frequency. First, it can Hilbert transform all IMF [7], namely:

$$H[c_i(t)] = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{c_i(t)}{t-\tau} d\tau \tag{4}$$

Structure analysis signal to obtain amplitude and phase function:

$$a_i(t) = \sqrt{c_i^2(t) + (H[c_i(t)])^2} \tag{5}$$

$$\Phi_i = \arctan \frac{H[c_i(t)]}{c_i(t)} \tag{6}$$

The instantaneous frequency is:

$$w_i(t) = \frac{d\Phi_i(t)}{dt} \tag{7}$$

So

$$x(t) = H(w,t) = \mathrm{Re}\sum_{i=1}^{n} a_i(t) \exp(j\int w_i(t)dt) \tag{8}$$

Here omit residual amount $r_n(t)$, Re represent the real component, and $H(w,t)$ become known as the Hilbert spectrum. Further define marginal spectrum as:

$$h(w) = \int_0^T H(w,t)dt \tag{9}$$

Here, T is the total length of signal. The instantaneous frequency and amplitude can be described as the time and frequency of the original signal, the Hilbert spectrum accurately describes the amplitude of the signal on the frequency changing with time and frequency, and $h(w)$ reflects the signal amplitude with the change of frequency in the whole frequency [8].

4. EXPERIMENTAL SIMULATION

In this paper, it adopts the vibration signal data from the USA Case Western Reserve University as the experimental simulation data, trying simulation and verification to prove the feasibility and effectiveness of the method. The bearing rotating speed of 1797 r/min, the sampling frequency is 12 kHz, the use of 1024 points. Fig. (1) shows the original abnormal vibration signal; Fig. (2) shows the original normal vibration signal. By looking at the frequency characteristics in Fig. (1) and Fig. (2), it can be obtained by significant changes occurred in the vibration amplitude. It indicates that the device does appear abnormal situation, but cannot determine the fault feature. So it needs for further analysis and processing for the original signal.

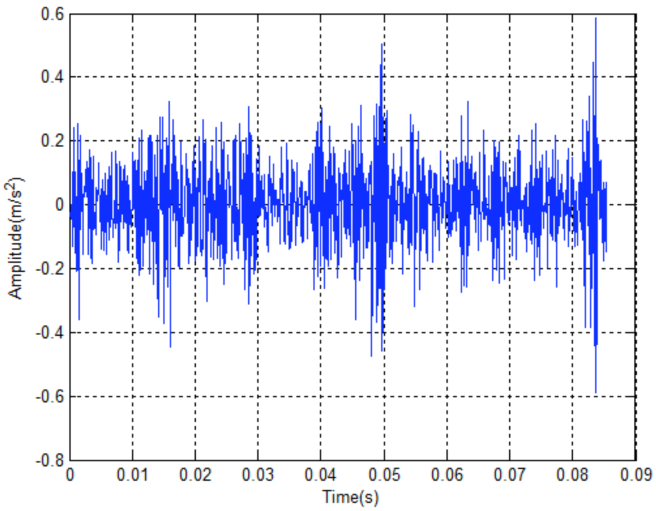

Fig. (1). Original abnormal vibration signal

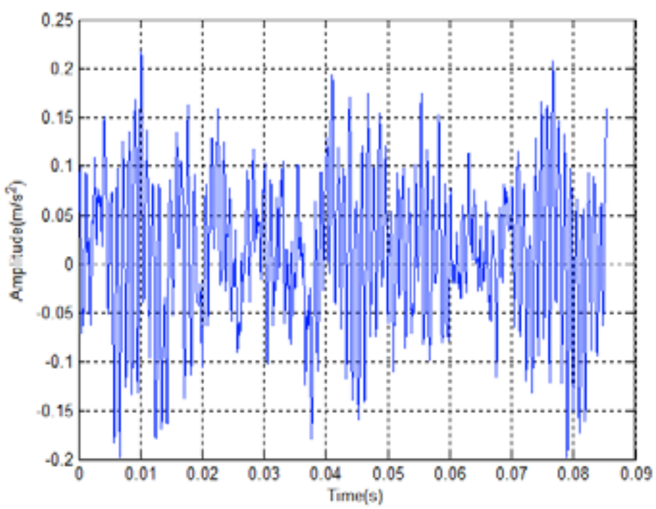

Fig. (2). Original normal vibration signal

In order to analysis and research the vibration signal further, it can obtain the corresponding vibration signal spectrum from the original signal by EMD decomposition, decomposition process as shown in Fig. (3). Fig. (3) is IMFs of abnormal vibration signal after EMD decomposition. It can be seen from Fig. (3), EMD decomposition is a vibration signal decomposition process from high frequency to low frequency one by one, abnormal vibration signal is reasonably decomposed into 7 IMFs and a residual amount Res, the frequency of each IMF gradually reduce from the top to bottom. Each IMF includes the unique band frequency characteristic, which is the characteristic frequency of the vibration signal failure that it provides a good basis for fault diagnosis of research. Here, it can abandon the residual amount of Res.

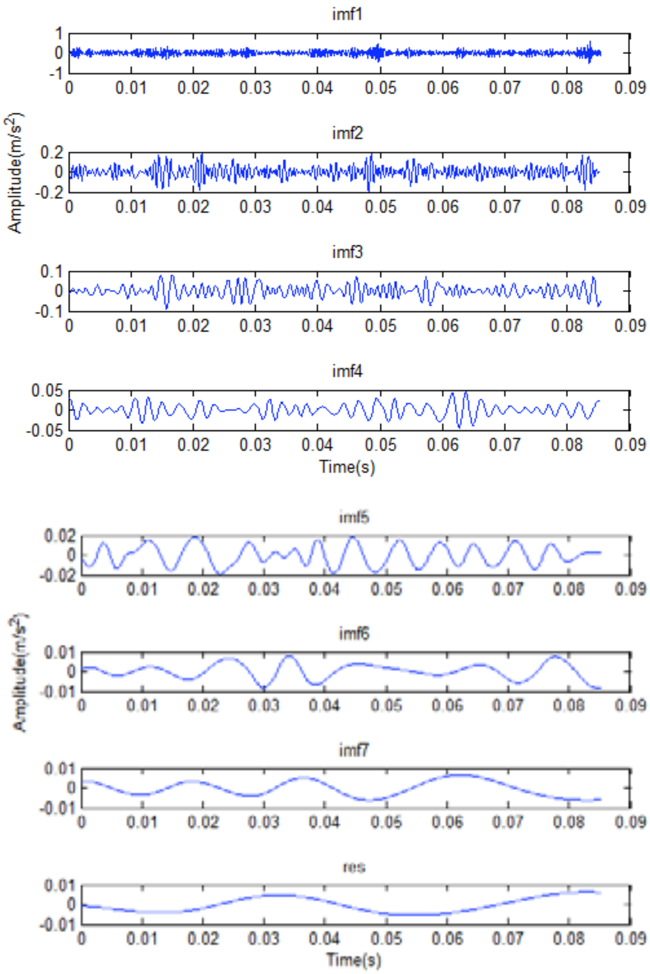

Fig. (3). IMFs of abnormal vibration signal after EMD decomposition

In the process of equipment fault diagnosis research, it can study the characteristics of each IMF to analyze the equipment running status by targeted, so that it achieves fault diagnosis. The changes of IMF1-IMF4 characteristics are very obvious, which contains rich vibration information. Therefore, this article takes IMF1-IMF4 as the main study objects to analyze the characteristics for fault diagnosis research and analysis.

Make use of Hilbert transform to deal each IMF, it can get the instantaneous frequency and instantaneous amplitude of each IMF to obtain signal’s Hilbert marginal spectrum, so as to realize the fault diagnosis. Here lists part analysis diagram. Fig. (4) is IMF1-IMF4 marginal spectrum of abnormal vibration signal. Fig. (5) is IMF1-IMF4 marginal spectrum of normal vibration signal.

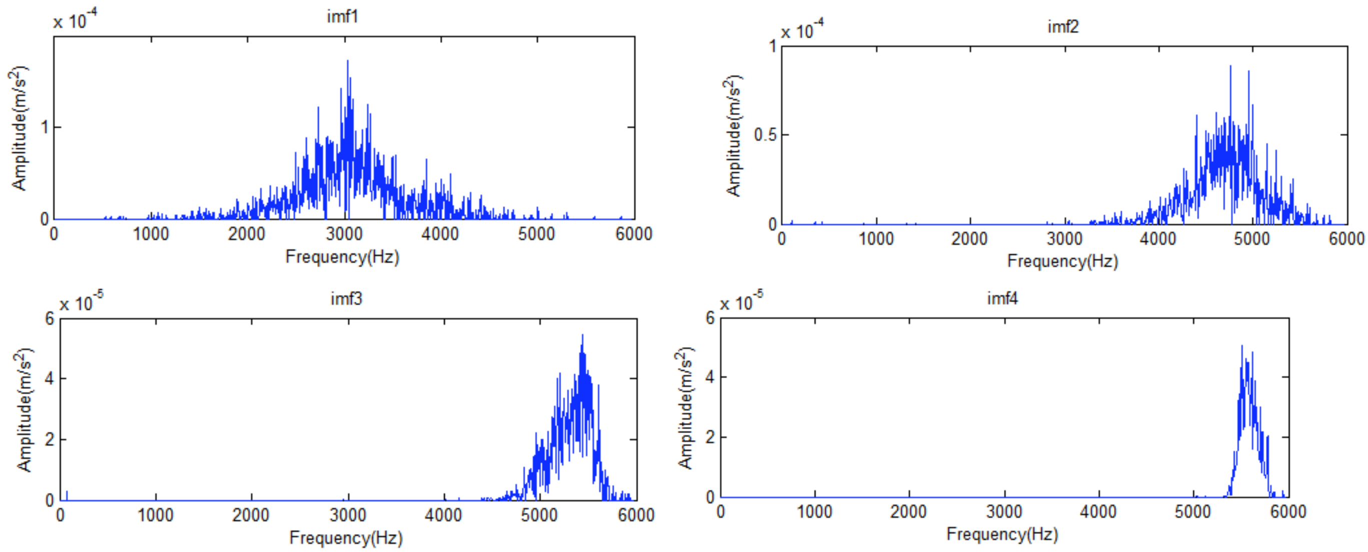

Fig. (4). IMF1-IMF4 marginal spectrum of abnormal vibration signal

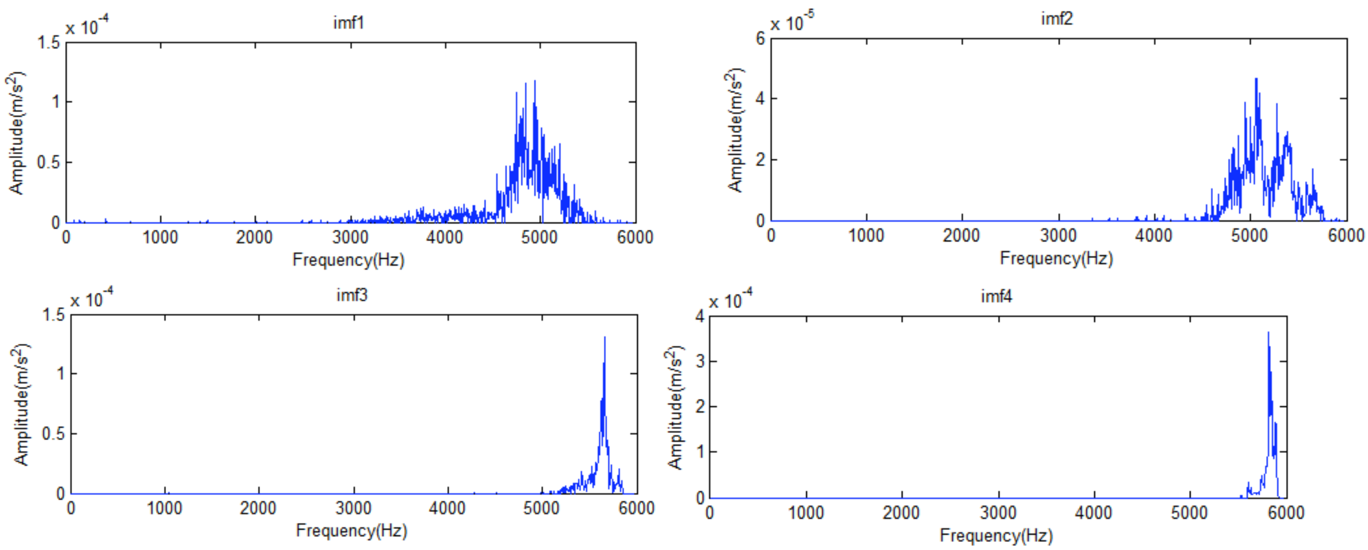

Fig. (5). IMF1-IMF4 marginal spectrum of normal vibration signal

By comparing and analyzing Fig. (4) and Fig. (5), it can be clearly concluded that the IMF1 vibration frequency of normal vibration signal focusing at 4500Hz to 5500Hz, while the IMF1 vibration frequency of abnormal vibration signal emerges a large number of abnormal vibration signal at 2000Hz to 4500Hz, and appears a peak at 3000Hz. There is surrounding accompanied by the emergence of the frequency doubling and frequency division, which is rich vibration information and powerful energy, so it is worthy of further research and analysis.

The IMF2 vibration frequency of normal vibration signal mainly focuses at 4500Hz to 5800Hz, while the IMF2 vibration frequency of abnormal vibration signal mainly focuses at 4000Hz to 5500Hz. So it emerges a large number of abnormal vibration signals, and the amplitude does significantly increase. Visibly, the frequency characteristics of the abnormal vibration signal has changed, especially the peak shifts from near 5000Hz to near 4800Hz, and it generates a lot of vibration energy information.

The IMF3 vibration frequency of normal vibration signal mainly at 5200Hz to 5800Hz, which is single peak and clear waveform, but while the IMF3 vibration frequency of abnormal vibration signal focusing at 4800Hz to 5800Hz, and there is a large number of abnormal vibration signal. It contains a lot of vibration feature information, and the amplitude has also been significantly increased. The IMF4 frequency of normal vibration signal and abnormal vibration signal concentrate at 5000Hz to 6000Hz, but the amplitude increases.

Visibly, IMF1-IMF4 marginal spectrum of equipment has significant changed, that is equipment problem, equipment management personnel needs to be targeted for fault diagnosis and analysis. By comparing and studying the changes of each IMF marginal spectrum, it can find the changes of characteristic frequency of equipment to locate the equipment fault position and improve diagnosis helpfully, so as to avoid fault diagnosis in blind. But to determine the equipment failure, it also needs to the next step to study for a specific frequency characteristics of the equipment failure in future.

7. CONCLUSION

The EMD has strong ability for processing unsteady and nonlinear signal. The simulation results show that the fault diagnosis of reciprocating piston diaphragm pump spindle, the HHT based on EMD method is effective and feasible. Through the analysis of marginal spectrum, it can accurately get the diaphragm pump spindle running status. Therefore, the HHT method based on EMD to fault diagnosis of reciprocating diaphragm pump spindle is of great significance.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

This work was financially supported by the foundation items: Science & Research Program of Sichuan province (No. 14ZB0339 & No. 15ZB0351); Science & Research Program of Aba Teachers College (No. ASC14-27 & No. ASC14-30).

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