The Fault Diagnosis of Rolling Bearing based on MED and HHT

Zhidong Wang
School of Mechanical Engineering, Shandong University,
Key Laboratory of High Efficiency and Clean Mechanical Manufacture, Shandong University,
Jinan , China
e-mail: wzdhbdjk@163.com

Daokun Zhang
School of Mechanical Engineering, Shandong University,
Key Laboratory of High Efficiency and Clean Mechanical Manufacture, Shandong University,
Jinan , China
e-mail: zhangdaokun1030@136.com

Rui Huo
School of Mechanical Engineering, Shandong University,
Key Laboratory of High Efficiency and Clean Mechanical Manufacture, Shandong University,
Jinan , China
e-mail:huorui@sdu.edu.cn

Abstract—As an essential part of rotating machinery, the early fault diagnosis of rolling bearing can improve the safety of mechanical operation. What's more, the machining accuracy can be effectively ensured. Unfortunately, the early fault signal of rolling bearing is extremely weak, which can be easily covered by others. And the endpoint effect will appear in several Intrinsic Mode functions (IMFs) when it is decomposed by Hilbert-Huang transform (HHT), which make it difficult to find the fault position accurately. To get the real components, the minimum Entropy Deconvolution (MED) method is proposed here to obtain the effective impact components with an inverse filter, which can improve the signal-to-noise ratio. The MED method which can effectively extract the useful information of the rolling bearing's fault signal, and fully suppress the endpoint effect of Empirical Mode decomposition (EMD), as well as greatly improve the ability to precisely find the fault position, which has been confirmed by a lot of experiments, which has a great practical value in the practical production.

Keywords- Rolling bearing; optimal filter; Minimum entropy deconvolution; HHT; Fault Diagnosis;

I. INTRODUCTION

According to a recent survey, it show that almost 30% [1]of mechanical failure during the operation process of rotating machinery caused by rolling bearing's fault. So it is of great significance to conduct the early fault diagnosis, through which safe operation and precision can be effectively guaranteed. Fault diagnosis contains two parts, one is feature components extraction and the other is fault identification. As all known, some useful methods such as fast spectral kurtosis [2-3], wavelet transform [4-5] have been widely used in feature extraction. But they can only effectively extract the fault signal of rolling bearing components on a certain degree. When it comes to strong noise background signals, they have a poor performance on fault component extraction. So the subsequent fault can't be accurately identified.

HHT [6-8] is an adaptive signal processing method based on local signal characteristics, consisted of two parts: Firstly, preprocessed signal decomposed by empirical mode decomposition (EMD) method into intrinsic mode function (IMF) series. Secondly, fault position identified according to its Hilbert spectrum. What troubles us most is that endpoint effect appears in the first and second IMFs decomposed by EMD, from which the fault position can't be found from their Hilbert spectrum. In order to solve the problem, minimum entropy deconvolution (MED) [10-11] which can effectively extract the spike pulse of weak signal proposed here to preprocess the early fault signal of rolling bearing collected, then real signal obtained. Combined with HHT method, the fault position can be exactly found.

II. BRIEF INTRODUCTION OF MINIMUM ENTROPY DECONVOLUTION

Minimum entropy deconvolution firstly proposed by Wiggins in 1978[12] to deal with the seismic reflection data, then applied in gear fault diagnosis by Endo. MED is an effect way to get the real signal from the signal acquired by looking for the right inverse filter.

Assuming that the system input x(k) is the sparse spike pulse sequence, which has simple characteristics. When it comes to a certain deterministic system, the entropy is smaller. Then output obtained:

$$z(k) = h(k) * x(k) \tag{1}$$

The signal will lose the characteristics of simple and certainty when it goes through the system, owing to the entropy increases clandestinely. The fundamental of MED is to look for a inverse filter g(l) on L order, through which the output y(k) could be restore the system's input x(k), that's is:

$$y(\mathrm{k}) = \sum_{k=1}^{L} g(\mathrm{l})\,\mathrm{z}(\mathrm{k}-\mathrm{l}) \approx \beta x(\mathrm{k}-\tau) \tag{2}$$

In order to get the characteristics of simple and certainty again, time delay and amplitude are allowed when get the real x(k) based on y(k), and the entropy decreases.

With the purpose of designing a optimal filter g(l) to make the entropy smaller, the objective function(equation(3)) equals zero(equation(4))

$$\mathrm{O}_4(\mathrm{g(l)}) = \sum_{i=1}^{N} y^4(\mathrm{i}) \Bigg/ \left[\sum_{i=1}^{N} y^2(\mathrm{i})\right]^2 \tag{3}$$

$$\partial(\mathrm{O}_4(\mathrm{g(l)}))/\partial(\mathrm{g(l)}) = 0 \tag{4}$$

Then we obtain:

$$\left[\sum_{k=1}^{N} y^2(\mathrm{k}) \Bigg/ \sum_{k=1}^{N} y^4(\mathrm{k})\right] \sum_{k=1}^{N} y^3(\mathrm{k}) z(\mathrm{k}-\mathrm{l}) = \sum_{p=1}^{L} g(\mathrm{p}) \sum_{k=1}^{N} \mathrm{z}(\mathrm{k}-\mathrm{i})\,\mathrm{z}(\mathrm{k}-\mathrm{p}) \tag{5}$$

When it meets equation(5), MED method can effectively capture the spike pulse components in the early and weak fault signal of rolling bearing. What excites us most is that shock signal can be restored perfectly.

III. HILBERT-HUANG TRANSFORM

Hilbert-Huang Transform mainly divided into two steps: signal decomposition and Hilbert spectrum obtention. Decompose signal to get IMFs is an important part of the HHT, and each IMF meets two requirements: (1) the number of poles and zeros' difference should be equals zero or one at most in the whole data. (2)The average value of envelope gained from the absolute maximum of upper envelope and lower envelope must be zero at any point, that's the upper envelope and lower envelope must be axisymmetric.

After first step, the relationship between signal components obtained:

$$x(\mathrm{t}) = \sum_{j=1}^{n} c_j + r_n \tag{6}$$

Where x(t) is the signal processed by EMD, c_j means IMF components, r_n means residual component after decomposition. And limited standard deviation (SD) chosen here to judge the whether the IMF obtention should come to an end or not. In this paper, the SD value ranges from 0.2 to 0.3.

The SD calculated from two consecutive IMFs chosen, just like equation (7).

$$SD = \sum_{t=0}^{T} \frac{\left[h_{k-1}(\mathrm{t}) - \mathrm{h}_k(\mathrm{t})\right]^2}{h_{k-1}^2(\mathrm{t})} \tag{7}$$

IV. ANALYSIS OF FAULT DATA COLLECTED

In this section, the methods mentioned above have been applied to deal with the fault data collected to find the accurate fault position of rolling bearing. First of all, the MED used to get the real shock signal, then EMD to get the IMF series. Correlation coefficient applied to select some appropriate IMFs, and their real failure frequency will be obtained by Hilbert spectrum. Compared with their theoretical failure frequency, the fault position will be identified easily (Figure 1.).

The geometric parameters of fault rolling bearing tested listed in Tab.1, and the theoretical failure frequency calculation formulas as follow(equation(8) and (9)).

TABLE I. GEOMETRIC PARAMETERS OF FAULT ROLLING BEARING TESTED

Pitch diameter （mm）	**diameter （mm）**	**elements number**	**contact angle (o)**
38.5	7.985	7.985	0

$$f_{outer} = \frac{z}{2}\left(1 - \frac{d}{D}\cos\alpha\right) f_r \tag{8}$$

$$f_{inner} = \frac{z}{2}\left(1 + \frac{d}{D}\cos\alpha\right) f_r \tag{9}$$

Where the D means pitch diameter, d means diameter, n means elements number, α means contact angle. fr=N/60，the N refers the input shaft's rotation.

When the speed N equals 800 r/min, the inner and outer theoretical failure frequency obtained by equation (8) and (9), finner = 72.4442 Hz, fouter = 47.5558 Hz.

A. Outer ring fault diagnosis

The fault signal collected (Figure 2.) of outer ring, which has been preprocessed by MED mentioned above shown in Figure 2. Comparing with Figure 2, the obvious shock components can be found easily, which means the MED can effectively restore te weak signal.

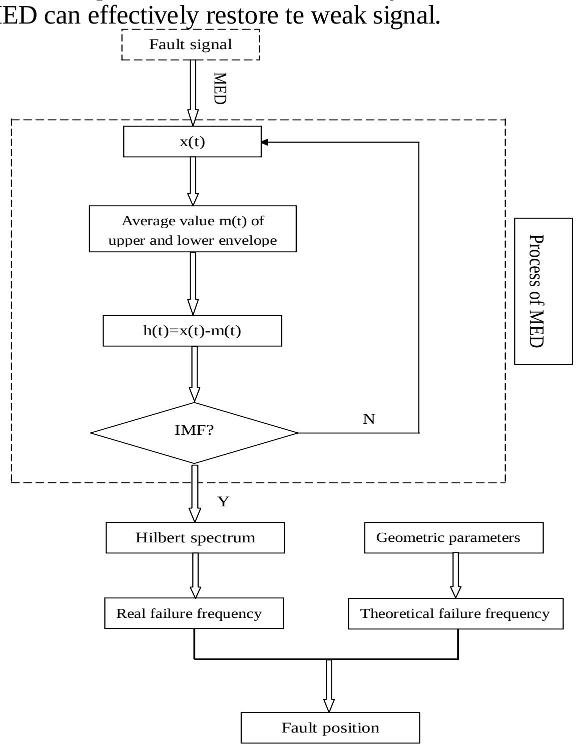


Figure 1. Specific flow chart of fault diagnosis

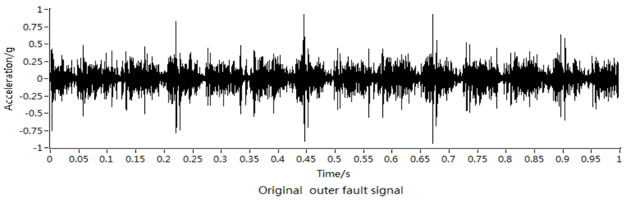


Figure 2. Original outer fault signal

Then the IMF series obtained by decomposing the preprocessed signal, and the first four IMFs chosen (Figure 4.) according to their correlation coefficients. From the Hilbert spectrum (Figure 5.) of the IMFs chosen, the real fault frequency obtained ranges from 47 Hz to 50 Hz, which is very closely to its theoretical fault frequency 47.5558Hz calculated by equation (8). So the fault position must be the outer ring.

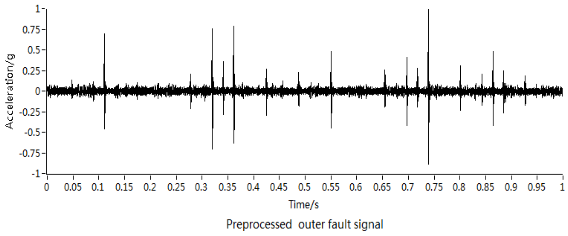


Figure 3. Preprocessed outer fault signal

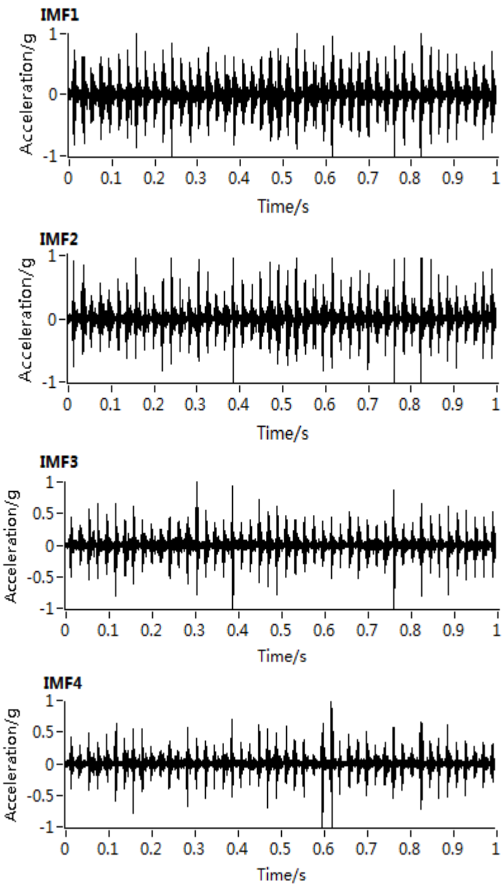


Figure 4. First four IMFs of outer ring

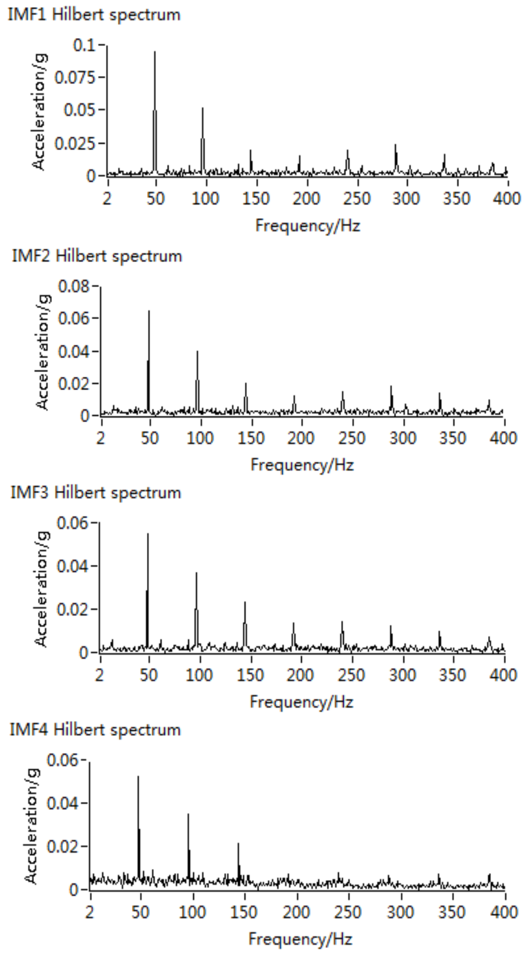


Figure 5. Hilbert spectrum of IMFs chosen

B. *Inner ring fault diagnosis*

The fault signal collected (Figure 6.) of inner ring, which has been preprocessed by MED mentioned above shown in Figure 7.With the methods above, the first four IMFs of inner ring chosen (Figure 8.) according to their correlation coefficients. From the Hilbert spectrum (Figure 9.) of the IMFs chosen, the real fault frequency obtained range from 71 Hz to 73 Hz, which is very closely to its

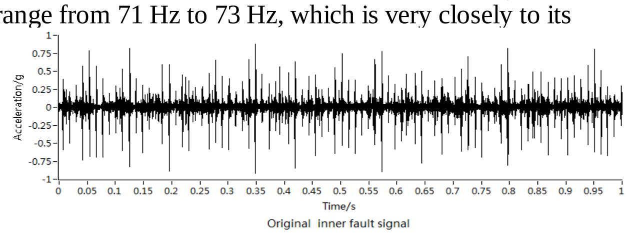


Figure 6. Original inner fault signal

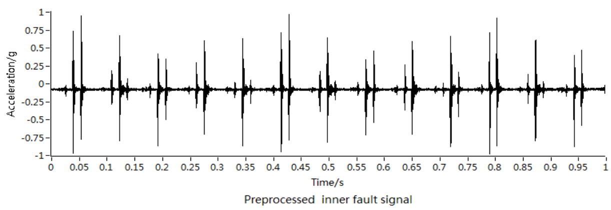


Figure 7. Preprocessed outer fault signal

theoretical fault frequency 72.4442 Hz calculated by equation (9). So the fault position must be the inner ring.

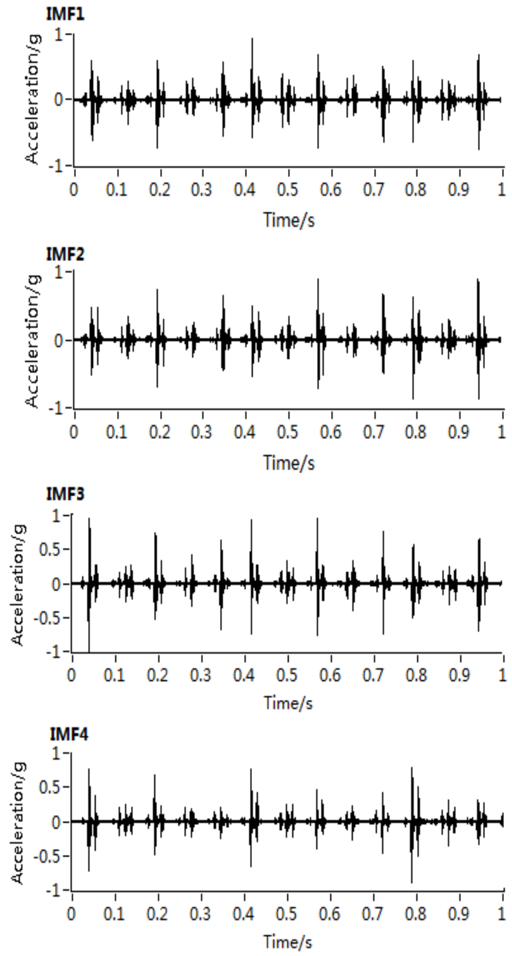
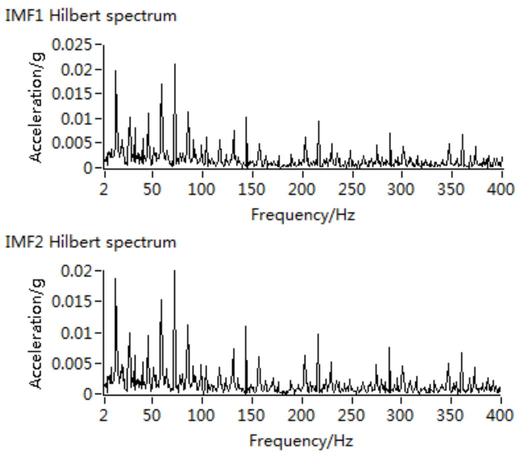


Figure 8. First four IMFs of inner ring



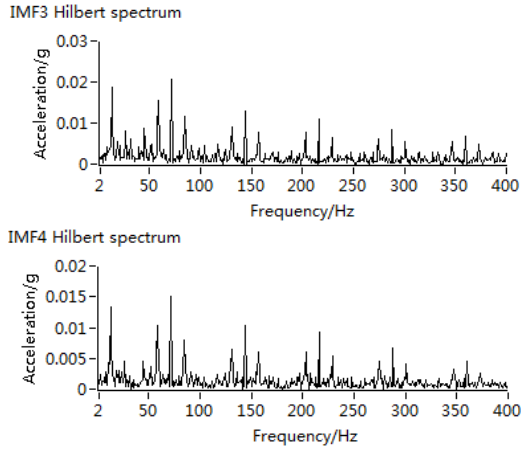


Figure 9. Hilbert spectrum of IMFs chosen

V. CONCLUSIONS

As known, it's very difficult to extract the effective components of early rolling bearing fault signal under the strong noise background. In this study, minimum entropy deconvolution (MED) combined with HHT applied to identify the fault position accurately of early rolling bearing. Lots of experimental results show that MED can effectively restore the weak shock signal under the strong noise condition. What's more, the endpoint effect the MED can be effectively restrained, which makes us find the fault frequency quickly and accurately. Comparing the real fault frequency obtained by the Hilbert spectrum of IMFs chosen with the theoretical failure frequency, the fault position can be identified accurately, which will greatly promoted the development of early fault diagnosis of rolling bearing technology.

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