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Frequency Demodulation Analysis of Mine Reducer Vibration Signal

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Abstract: The spectral structure complexity of the Mine Reducer vibration signal was analyzed. The basic theory of the vibration signal frequency demodulation analysis was introduced, The essential mode function which met the single component requirement was obtained by using Empirical mode decomposition in the Hilbert Huang Change. The instantaneous frequency was calculated, The spectrum of the instantaneous frequency was obtained by performing the Fast Fourier Transform, The spectrum analysis was done.

Keywords: Mine Reducer, Frequency Demodulation, Hilbert Huang Change, Essential Mode Function, Instantaneous Frequency, Spectrum

1. Introduction

As a core part of the mining equipment drive system，Mine Reducer has a higher failure rate, Maintenance is difficult and expensive because the operating conditions of the Mine Reducer is complicated and wicked. [1] Vibration Testing Analysis is still one of the common methods for Mechanical Fault Diagnosis at present. [2] However, The difficulty of vibration signal analysis and fault diagnosis is increased, because the complex time-varying modulation characteristics of planetary gear box vibration signal. [3]

The Mining Equipment operate in a complex wicked and heavy haul environment. As the speed change mechanism in the driveline of the mining equipment Reducer, The Mine Reducer has complicated structure. It usually includes multi-speed transmissions with different transmission ratios and planetary gearbox which is Made up of sun gear, planetary gears, ring gear and planet carrier. [4] In addition, The Mine Reducer includes bevel gear pair which is used to change the drive direction. The vibration signal of the Mine Reducer is complicated. Firstly the signal components are complicated, which contain the characteristic frequency component of each component and the coupled vibration signal of the power input device and load equipment, The vibration Signal is also includes background noise. Secondly the vibration signal has Nonstationarity and modulation features. The signal waveform not only includes harmonic wave and impact characteristics but also includes multiple components modulation and time-varying modulation. [5]

Therefore, this paper selects a mine gear reducer as the research object. By applying the Empirical mode decomposition method in Hilbert-Huang Transform, The intrinsic mode functions which satisfy Single-component condition were obtained, The instantaneous frequency was calculated, The instantaneous frequency spectrum of the Mine Reducer vibration signal has been obtained by performing the Fast Fourier Transform, The spectrum analysis has been done.

2. The Method of Frequency Demodulation Analysis

2.1. The Basic Theory of the Frequency Demodulation Analysis

Modulation is the process which makes certain parameters of a signal change under the control of another signal, The previous signal is called carrier signal and the latter signal is called modulation signal. Demodulation is the process which recovers the original signal from the modulated wave. [6]

According to the modulated parameters of the carrier, the modulation can be divided into amplitude modulation, frequency modulation, and phase modulation.

The vibration signal frequency modulation of planetary reducer contains only frequency components which caused by gear failure and is not affected by changes in the vibration transfer path. Therefore, the frequency modulation component not only contain the information of the reducer fault, but also has a simpler frequency component.

In 1998, Norden E. Huang and others proposed an empirical mode decomposition method and introduced the concept of Hilbert spectrum and the method of Hilbert spectrum analysis. NASA named this method the Hilbert-Huang Transform. It consists of two parts, The first part is empirical mode decomposition which was proposed by Norden E. Huang. The second part is Hilbert spectrum analysis. [7]

The basic steps of the frequency demodulation analysis method based on empirical mode decomposition are as follows:

1). In order to meet the single-component requirement for calculating the instantaneous frequency, an empirical mode decomposition is applied to decompose the signal into an essential mode function.

2). Calculate the instantaneous frequency of each essential mode function based on the Hilbert transform;

3). The Fast Fourier Transform of the instantaneous frequency of the selected essential mode function was done, The Diagnosis of reducer fault was done according to the peak frequency in the Fourier spectrum of the instantaneous frequency and the fault characteristic frequency of each gear

2.2. The Method of the Essential Mode Function Calculation

The Frequency Demodulation Analysis is done by Selecting the Essential Mode Functions which are first decomposed and the instantaneous frequency fluctuates around the meshing frequency and the multiplier of meshing frequency. There are three reasons for the above Selecting. Firstly, the empirical mode decomposition extracts essential mode functions in descending order of frequency; Secondly, the impact characteristics caused by gear failure are more obvious in the high frequency range; Lastly, the carrier frequency of the gear vibration signal is the mesh frequency or its frequency multiplication. The intrinsic mode function in which the instantaneous frequency fluctuates up and down around the meshing frequency or multiples contains gear failure information. The essential mode function is similar to the basis function in Fourier transform and wavelet analysis, But it has no fixed expression, It is determined adaptively based on the fluctuation of the signal. Therefore it is suitable for calculating the instantaneous frequency. [8]The essential mode function satisfies the following two conditions:

1). In the entire data set, the number of extreme points and zero crossings is equal or at most 1;

2). The mean value of the upper and lower envelopes defined by local maxima and local minima is zero at any time.

Condition 1) similar to the traditional narrowband requirements of the Stationary Gaussian Process, Condition 2) Change the traditional global requirements to local requirements, Transient frequency fluctuations caused by asymmetrical waveforms is avoided.

The Empirical Mode Decomposition is complete and adaptive, and in practical applications, it is almost orthogonal. The Empirical Mode Decomposition extracts Essential Mode Functions sequentially in descending order of frequency at any moment.

This method requires that the signal meet the following assumptions.

Firstly the signal contains at least 2 extreme points, one maximum and one minimum, that is, the signal contains fluctuating components;

Secondly characteristic time scale is determined by the time interval between extreme points, in this way, you can get a higher-resolution oscillation mode which applies to the situation where the mean is non-zero and there is no zero crossing;

If there are only inflection points in the data, there are no extreme points. The extreme points can be extracted by using the differential, The final result is obtained by integrating. However, the actual data contains noise. Differential will amplify the interference effect of noise, The recommends from the practical application experience are as follows: At first, screening is done which based on the extreme point, If the result contains an implied scale, Then differential screening is done.

For the actual signal $x\ (t)$, the specific algorithms for empirical mode decomposition are as follows. [9]

1) Initialization: It is assumed that residual signal $r_0(t)=x\ (t)$, $i=1$.
2) Filtering the i-th essence mode function: *a*) initialization: it is assumed that $j=0$, $h_{ij}\ (t)=r_{i-1}(t)$; *b*)

The local maxima and local minima of $h_{ij}\ (t)$ is determined; *c*) Interpolation is done by applying cubic splines. The top and bottom envelopes of $h_{ij}\ (t)$ are constructed from local maxima and local minima respectively; *d*) The instantaneous mean m_{ij} (t) of the upper and lower envelopes is calculated; e) It is assumed that $h_{ij}\ (t)= h_{ij}\ (t)- m_{ij}\ (t)$, If $h_{ij}\ (t)$ satisfies the termination condition of the essential mode function screening, It is assumed that the i-th essence mode function $c_i\ (t)= h_{ij}\ (t)$, otherwise, It is assumed that $j=j+1$, Return to step b).

3) It is assumed that $r_i\ (t)= r_{i-1}\ (t)- c_i(t)$
4) If $r_i\ (t)$ satisfies the termination condition of the empirical mode, Then residual signal is $r_i(t)$ and the decomposition process is over. Otherwise, It is assumed that $i=i+1$, Return to step 2).

2.3. The Method of the Vibration Signal Instantaneous Frequency Calculation

For an essential mode function that satisfies a single-component requirement, the instantaneous frequency of it is calculated by local phase differential method through

Hilbert transform. For real signals *x* (*t*) which meet single-component requirements, the analytical signal is as follows: [10]

$$z(t)= x(t)+ jy(t)= a(t)\exp\ [j\alpha(t)] \tag{1}$$

Where y (t) is the Hilbert transform of x (t)

$$y(t) = \frac{p}{\pi}\int_{-\infty}^{\infty}\frac{x(\tau)}{t-\tau}d\tau \tag{2}$$

P is the Cauchy main value, a (t) is the instantaneous amplitude.

$$a(t)=[\ x^2(t)+ y^2(t)]^{1/2} \tag{3}$$

γ (t) is the instantaneous phase

$$\gamma(t)=arctan\ [y(t)/\ x(t)] \tag{4}$$

$$\phi(t) = \arctan\left[\frac{y(t)}{x(t)}\right] \tag{5}$$

For single-component signals, the instantaneous frequency is defined as the differential of instantaneous phase-to-time

$$f(t) = \frac{1}{2\pi}\frac{d\alpha(t)}{d(t)} \tag{6}$$

The Hilbert transform of the essential mode function that was first decomposed was done. The instantaneous frequency was calculated by the local phase differential method.

2.4. Frequency Spectrum Analysis Method of Instantaneous Frequency

The method of describing the signal in terms of frequency is called the frequency domain description of the signal. The transformation of the signals from time domain descriptions into frequency domain descriptions is called the time-frequency domain transformation of the signal, The time-frequency domain transformation method of periodic vibration signals is decomposed by the Fourier series expansion method. The time-frequency domain transform method of non-periodic vibration signals is done by the Fourier integral method, Both of them are called the Fourier transforms. [11]

From the formula of the discrete Fourier transform, it can be seen that if the sampling data is N calculating a frequency data requires N complex multiplication operations and N-1 complex addition operations, Calculating all frequency domain data requires N^2 complex multiplication operations and N (N-1) complex addition operations. Multiply operations on general computers are much slower than addition operations. Due to the amount of calculation is too large and the cost of calculation is too high. The Fourier transform lacks practicality especially in real-time analysis of spectrum. [12]

Fast Fourier transform is a fast algorithm of finite sequence discrete Fourier transform. It reduces the number of operations required to perform a discrete Fourier transform greatly. Due to the reduction in the number of operations, Computing time is reduced and computer efficiency is improved, Real-time processing of vibration signals is been done.

N-point discrete Fourier transform of the N-sequence x (r) can be expressed as follows

$$X(k) = \sum_{r=0}^{N-1} x(r)W^{kr}\,(0 \le k \le N-1) \tag{7}$$

among them

$$W = e^{-j2\pi/N} \tag{8}$$

Utilizing the periodicity of factor W^{kr}

$$W^{kr} = W^{k(r+N)} = W^{(k+N)r} \tag{9}$$

Some items in the discrete Fourier transform operation can be combined.
its symmetry can be drawn as follows

$$W^{kr+N/2} = -W^{kr} \tag{10}$$

By using its symmetry and periodicity, the discrete Fourier transform of long sequence can be decomposed into a short sequence discrete Fourier transform.

3. The Result of the Mine Reducer Frequency Demodulation

3.1. The Calculation of the Essential Mode Function

The vibration acceleration time domain signal of measuring points in the high speed box bearing which was obtained by mining reducer vibration test was imported into MATLAB, Applying the empirical mode decomposition method of the Hilbert Transform, The signal processing program is prepared by using MATLAB software, The empirical mode decomposition of the vibration acceleration signal is done. The essential mode functions of the vibration acceleration signal is extracted in descending order of frequency. A total of 11 essential mode functions and a residual component are generated as shown in Figure 1.

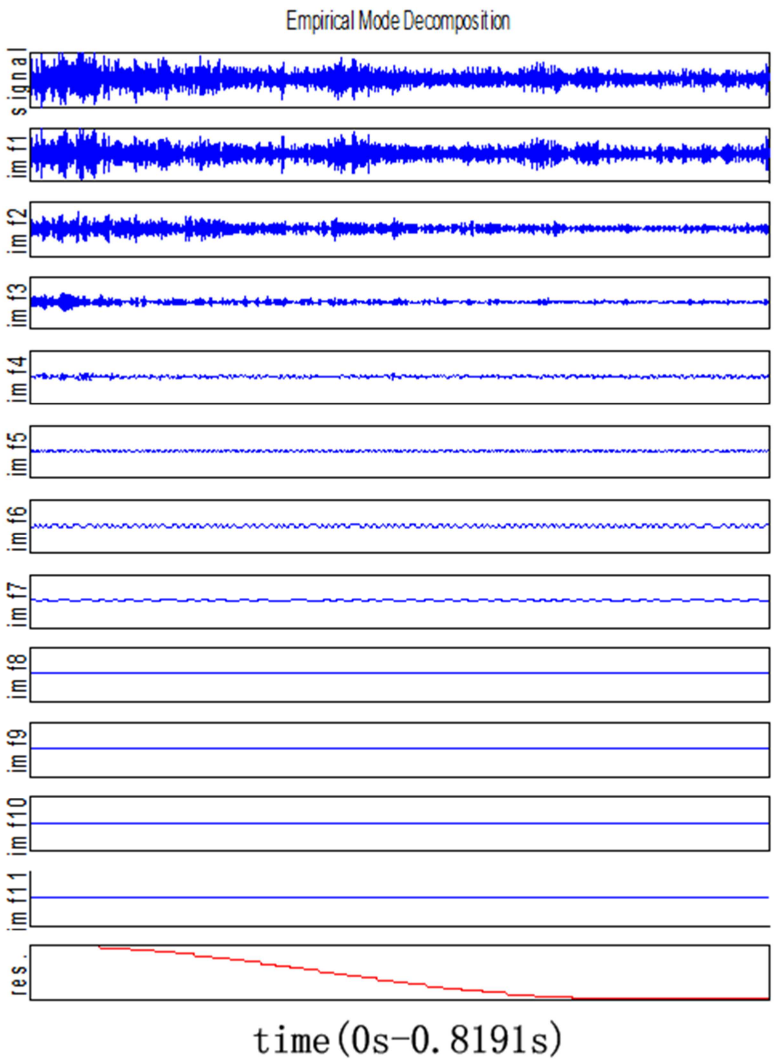

Figure 1. *Essential mode function time domain waveform.*

The essential mode function which was decomposed firstly is shown in Figure 2:

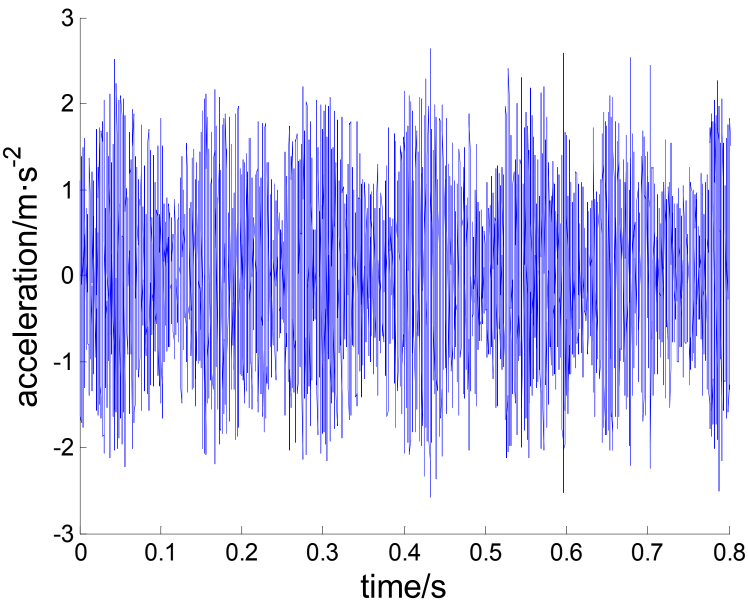

Figure 2. *The first essential mode function time domain waveform.*

3.2. The Calculation of the Vibration Signal Instantaneous Frequency

The Hilbert transform of the essential mode function that was first decomposed was done. The instantaneous frequency was calculated by the local phase differential method. The MATLAB calculation program was Prepared, The time domain waveforms of the essential mode function was generated, it was shown in Figure 3.

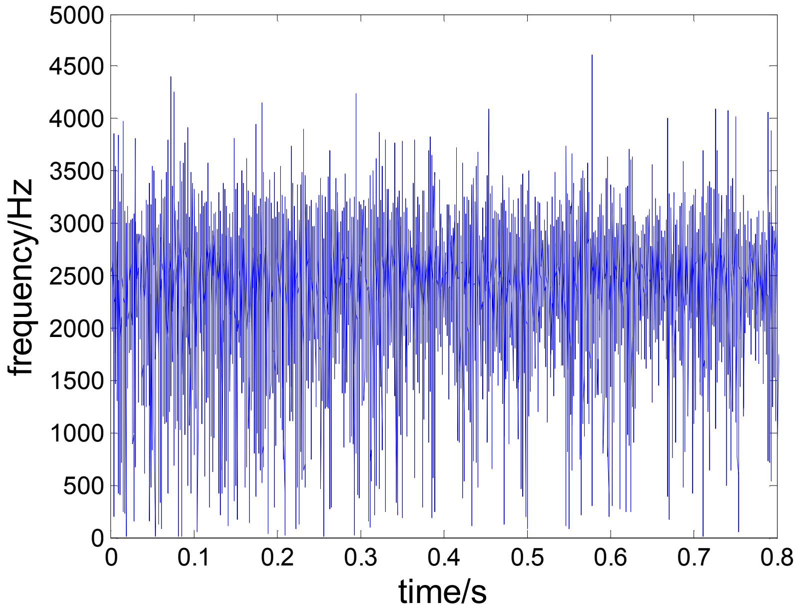

Figure 3. *Instantaneous frequency of essential mode function.*

3.3. Frequency Spectrum Analysis of the Instantaneous Frequency

Selecting the instantaneous frequency of the essential mode function which was obtained by the first decomposition as the study object. A fast Fourier transform was performed on the waveform of the time domain vibration signal. The spectrum of the instantaneous frequency is shown in Figure 4.

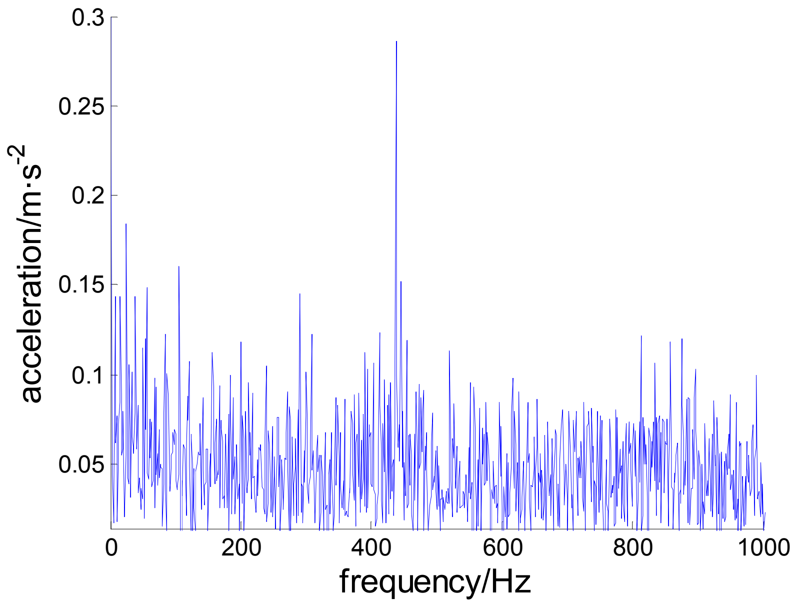

Figure 4. *Spectrum of instantaneous frequency.*

The statistics of the frequency spectrum of the instantaneous frequency is shown in Table 1.

Table 1. *Spectrum component statistics of instantaneous frequency.*

frequency/Hz	448.2	24.4	106.2	296.5
Amplitude/m·s^{-2}	0.2863	0.1839	0.1604	0.1452

4. Discussion

According to Figure 2, the time-domain waveform of this instantaneous frequency fluctuates around 2500 Hz. According to the design parameters of the mine reducer, the meshing frequency of the first gear pair is approximately 500Hz. The instantaneous frequency fluctuates around 5 times the frequency of the first gear pair meshing frequency.

The instantaneous frequency is calculated from the intrinsic mode function which was obtained by the first decomposition. From the frequency domain demodulation analysis theory of the planetary reducer vibration signal It was be found that the instantaneous frequency may contain gear fault information.

According to the design parameters of the mine reducer, the gear meshing frequency of the first gear is 445Hz and the input shaft rotation frequency is 25Hz, So the main frequency component of this instantaneous frequency spectrum is the frequency of one-stage gear meshing frequency and input shaft rotation frequency and frequency multiplication. Among them, the amplitude of 448.2 Hz is the largest one and the amplitude is 0.2863 m·s-2, the amplitude of 296.5 Hz is the minimum one and the amplitude is 0.2863 m·s-2, the former is 1.97 times larger than the latter. From this, it is concluded that the meshing frequency of the first gear pair of the Mine reducer constituted the dominant component of its vibration spectrum. It is known that the amplitude of the dominant frequency does not exceed the fluctuation range of the normal reducer by comparing vibration parameters of several reducers. Therefore, it was judged that there was no abnormality in the mine decelerator.

5. Conclusion

The basic theory of frequency demodulation analysis of vibration signals was described. Taking the mine reducer as the research object, a frequency domain demodulation analysis was performed on it. Its essential mode function and instantaneous frequency were calculated, the spectrum of the instantaneous frequency was generated by applying the fast Fourier transform. According to the design parameters of the reducer, the frequency spectrum analysis of instantaneous frequency was done. The conclusions are as follows:

The vibration acceleration signal of the mine decelerator was decomposed to 12 essential mode functions. The instantaneous frequency of the intrinsic mode function which was obtained firstly fluctuates around the mesh frequency of the first gear pair of the reducer.

The meshing frequency of the first gear pair of the mine decelerator constitutes the dominant component of the instantaneous frequency vibration spectrum.

Compared with the amplitude of other frequency components, the amplitude of the dominant frequency did not exceed the fluctuation range of the normal reducer. Therefore, it was judged that there was no abnormality in the mine decelerator.

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