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HHT Time-Frequency Energy Spectrum Technique Used in Main Joints Condition Monitoring of QCC Track

YIN Yinan\textsuperscript{a}, HU Xiong\textsuperscript{b,a}\textsuperscript{*}

\textsuperscript{a} Shanghai Maritime Academy, Yuanshen Road 158, Shanghai, China
\textsuperscript{b} Shanghai Maritime University, Haigang Avenue 1550, Shanghai, China

Abstract

According to the quayside container crane (QCC), when the trolley passes by the tracks, the vibration which has features including heavy-load, high-speed and huge-impact happens. The Time-Frequency Energy Spectrum Technique based on Hilbert-Huang Transform (HHT) is put forward in this paper which is used to analyze this vibration. The application to the large-scale cranes belonged to a Shanghai container company shows that this technique can effectively monitor and evaluate the conditions of the QCC tracks and it is a new method for the monitoring and maintenance.

Keywords: Hilbert-Huang Transform; Time-Frequency Domain; Energy Spectrum; main joints; trolley track; condition monitoring

1. Introduction

The quayside container crane (the “QCC”) plays an important role in Container-Transport which becomes one of major forms in the logistic globalization. There are certain impact and vibration occurring while the trolley passes by the main joints which are connections between front girders and back girders. The deterioration of the main joints’ performance condition will increase the impulsive vibration and threaten the safety of the structure. Consider that in contrast, the non-joint parts of tracks are in better performance condition, therefore the repair and maintenance mainly focus on the main joints. How to evaluate the overall performing according to the condition monitoring and fault diagnosis of the trolley tracks, especially to the parts of main joints has important practical significance. It can ensure safe operation, and reduce the potential maintenance costs.

In traditional methods, Windowing Fourier Transform is used to analyze signals of the same characteristic scales \cite{2}. Because the size of time-frequency windows is fixed, the windows have no

\textsuperscript{*} E-mail address: enan.yin@gmail.com
adaptivity. Therefore, this method is not suitable to analyze the real-time signals of different characteristic sales and abrupt variations. Wigner-Ville Distribution has good time-frequency aggregation and symmetry but can’t ensure non-negativity. Furthermore, because it produces cross terms which could cause that the resolution radio falls off remarkably. The available range of this method is very limited. Recently, The Wavelet Transform analysis method has been used widely. Because of locality and multi-scale the Wavelet Transform can offer local information both in time and frequency domain to analyze the signals. However, this method is an adjustable window Fourier Transform in essence. It could omit energy because the length of the wavelet basic functions is finite. It is very difficult to analyze the real-time signals accurately in time and frequency domain by this method. In addition, when the wavelet basic function and decomposition scales are chosen, the result is a fixed frequency signal only related to the sampling frequency not to the signal itself. Therefore, the Wavelet Transform doesn’t have the adaptability [1][4].

The Hilbert-Huang Transform is an adaptive signal analysis method[1], mainly for non-linear and non-stationary signals. It is an exact decomposition method for vibration signals but there is no obvious conclusion for introduction and operation. Even the analysis of partial spectrum is mostly used in the fault diagnosis for the rotating machines just like gears and bearings. But the characteristics of trolley-track vibration signals of the large-scale QCC are non-linear, non-stationary and non-periodicity. Therefore in this paper, based on this method, Time-Frequency Energy Spectrum Technique is put forward.

2. The Proposition of HHT Time-Frequency Energy Spectrum Technique

In 1998, Norden E. Huang [1] proposed the method of Empirical Mode Decomposition (EMD), and introduced the concept and the analyzing method of the Huang Spectrum based on the Hilbert Transform which was named Hilbert-Huang Transform by NASA, referred to as HHT. Since inception, the EMD method with many excellent properties included the adaptability, orthogonality and completeness has been widely used in many areas. By this method, the vibration signal is decomposed into a number of Intrinsic Mode Function (IMF) components. If the functions are Intrinsic Mode Function (IMF) components must meet the two demands as follows:

(1) The number of zero points and extreme points must be equal or a point in difference in the continuance of the input signals.

(2) The mean of the super wrapping lines composed by the local maximum and the infra wrapping lines composed by the local minimum is zero at any time.

Aiming at the features of the trolley-track vibration signals of the QCC, HHT Time-Frequency Energy Spectrum Technique is put forward in this paper and the process of this technique is shown in Fig. 1.

![Image of process](image-url)
3. Engineering Application

A Shanghai container company does improvements to the tracks. The main joints are the points of the worst performance conditions in the entire tracks because there are a certain height differences between the main joints in the left and right side of the track that will inspire dramatic high-frequency vibrations when the trolley passes here. After a considerable period of time, the main joints have general wear and tear because of numerous times of the trolley reciprocating. Under normal circumstances, the method of patch weld is chosen in order to repair worn surfaces. (Patch weld on both sides of the joint respectively, fill the gap of wear and tear, and polish the surface of hinge points smoothly.) This approach can make the joints recover smooth in a short time in order to lower the vibration. But the welding department, after all, added as a part of the track, in the case of inclement conditions will gradually fall off, so we must re-repair welding to prevent the formation of a larger gap.

3.1 Analysis of Differences between Before and After Welding

In order to understand the influence of the surface desquamation on the performance conditions of the track, the real-time signals are acquisitioned based on NetCMAS (Crane Monitoring & Assessment System researched by Shanghai Maritime University) (in Fig.2). When the trolley of #QCC8107 is in the light-load operating conditions, from sea side to land side, the sampling time is 3.5s and the sampling frequency is 10 kHz.

The main joint in the track before and after the re-repair welding is respectively shown in Fig.3(a) on 12th July and Fig.3(b) on 3rd Nov. 2011. In Fig.3(b), the surface of the trolley-track is more smoothly after welding, therefore, when the trolley passes here, the vibration could be smaller theoretically.

There are six clear impacts at the main joints in the trolley-track vibration signals (in Fig.4(a)) which are provided by the front and back wheels of the trolley respectively through the three main joints of the track. In Fig.4(b), there are only two impacts when the wheels pass the main joint. Intuitively, the vibration of the whole crane is improved after welding.

Firstly, the time-domain vibration signals are analyzed with the method of EMD in according to the Fig.1 and then the each-level IMF component is derived respectively for the time-frequency energy spectrum analysis (The Fig.5 shows the results of the EMD, in Which the $c_1 \ldots c_7$ are IMF components of every level frequency and ‘r’ is the residue. Furthermore, $c_1 \ldots c_3$ are the high-frequency components.). The $c_1$ energy spectra are calculated respectively (in Fig.6), and we use the time-domain energy spectrum to explain the conclusions more clearly as follows.

Through the comparison between the two spectra it is found that the energy of main joints in the track before welding significantly higher than that after welding and there are serious high-energy impacts. The IMF components are analyzed with HHT method and the energy spectra are obtained in frequency domain (in Fig.7). There are several bulge crests in the vibration signals. Compared with the Fig.7 (a)
and (b), the vibration energy after welding is more evenly distributed with the variation of the frequency. Therefore, it can be concluded: the condition of the track after welding is much better.

3.2 Analysis of surface desquamation

The #QCC8103 is chosen to reseached. The Fig.8(a) and (b) respectively show the photos of the main joints in the left and right side of the track. From the two figures we can see some differences between the left and right main joints clearly: there is a large-area surface desquamation on a main joint in the left side.

Based on HHT Time-Frequency Energy Spectrum Technique, the results are shown in Fig.9 and Fig.10. In Fig.9, through the comparison between the two spectra it can be found that the energy of main joints in the left side of the track significantly higher than that in the right side and there are serious high-energy impacts.

It demonstrates that the surface desquamation has caused some influence in the left side of the track and the vibration of the left side is much greater than that of the right side. Therefore, the main joints in
the left side have a serious threat to the track security and it is necessary for maintenance to the surface desquamation. Furthermore, compared with the Fig.10 (a) of the frequency-domain energy spectra, in the Fig.10 (b), the vibration energy of the right side is more evenly distributed with the variation of the frequency, therefore, the consideration of the right side of the track is better than that of the left side. It can be concluded: the right side is “Normal” and the other side is “Fault”.

4. Conclusion

(1) HHT Time-Frequency Energy Spectrum Technique is put forward in this paper. The information can be extracted effectively from the trolley-track vibration signals by this technique.

(2) The main joints are the points of the worst performance conditions in the entire track, therefore, the features of the track vibration is included heavy-load, high-speed and huge-impact. By means of EMD, the real-time signals of the quayside container crane can be decomposed effectively.

(3) The trolley-track vibration can be classified to the conditions of “Normal” and ”Fault” from the fault information which is extracted by HHT Time-Frequency Energy Spectrum Technique, so this technique is a new method for the condition monitoring and maintenance of the trolley-track vibration.

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References

[1] Huang,N.E.,Shen,Z.,Long,S.R.,Wu,M.C.,Shih,H.H.,Zheng,Q.,Yen,N-C.,Tung,C.C., and Liu,M.H.(1998) The Empirical Mode Decomposition and Hilbert Spectrum for Nonlinear and Nostationary Time Series Analysis. Proc. Roy. Soc. Lond., Vol. A454, pp. 903-99

[2] Y. Dejie, C. Junsheng, Y. Yang, Application of EMD method and Hilbert Spectrum to the fault diagnosis of roller bearings. Mechanical Systems and Signal Processing. 2005: 259-270

[3] YIN Yinan, HU Xiong. (2007) Hilbert-Huang Technique to Abstract The Important Information of Weak Signals of Bearings. Journal of Vibration and Shock

[4] LI Hui. Discussion for online diagnosis and preventive production of motor faults. Electric Drive Automation. 2010,32(3).