International Journal of Control and Automation
Vol. 9, No. 5 (2016), pp. 91-98
http://dx.doi.org/10.14257/ijca.2016.9.5.09

Experimental Research on Fault Location for the Axle of Railway Vehicles Based on Acoustic Emission Technique

Chang Hong Jiang[1],Su Pan[2],Chao Zhang[3],Fu Li[4]

[1]Institute of Electrical and Electronics Engineering, Changchun University of Technology,Changchun,130012,P.R.China,
[2]Department of Orthopedics, the Second Hospital of Jilin University, Changchun, Jilin Province, China,
[3]School of Electronic and Information Engineering, Chang Chun University, Chang Chun, China,4.Portland State University
Email :jiangch@mail.ccut.edu.cn

Abstract

This paper proposes a method of fault position detection and location for the axle of railway vehicles, which based on Acoustic Emission technique. The method is used to denoise the Acoustic Emission signal by wavelet transformation and makes signal of continuous processing by Butterworth filter; then finds the maximum in reverse direction after taking threshold comparison with continuous signal in order to form the point of the first peak. Finally fault location is on the basis of the time from the first peak to the sensor. The experimental results indicate that the method can remove interference effectively and its positioning accuracy is better than the location method of Gabor transformation. After all, this method has a great value in engineering application.

Keywords: *Railway vehicles, Axle, Fault, Location, Wavelet*

1. Introduction

The working environment of railway vehicles is severe, wheelsets as the walking parts of the railway vehicles and is even effected by impact, cyclic stress, friction and high-low temperature forces, commonly lead to damage phenomenon such as wearing, crack and stripping. Usually railway bus and freight car use rolled steel wheelsets, which have a complex force condition during operation process. It's easy to enlarge and develop constantly, finally get broken shaft, cracking and exfoliated, due to the defects making in manufacturing process, then the traffic accident occurs[1,2]. In order to find the facility fault in time, maintain it effectively and guide production correctly, a method of fault location for the axle of railway vehicles needs to be solved urgently.

We can use time-difference method to find the location of sound source because of the axle is linear structure. This method use the time difference that waveform arrived two sensors, which come from sound source. And the location of sound source has determined according to the propagation speed that sound wave in the material. Although Acoustic Emission signal is easily noise-infected in the transmission process, we can ensure the effectiveness of signal in the transmission process by translation invariant wavelet transform de-noising technology [3].

2. Test Establishment

Test sample is rolled steel that the same material as axle, and the geometric parameters are illustrated in Figure1. We make a $45°C$ v-shaped notch in the middle of the samples at

ISSN: 2005-4297 IJCA

the first step, and then make a fine cracks which distance to the upper end is 15mm.

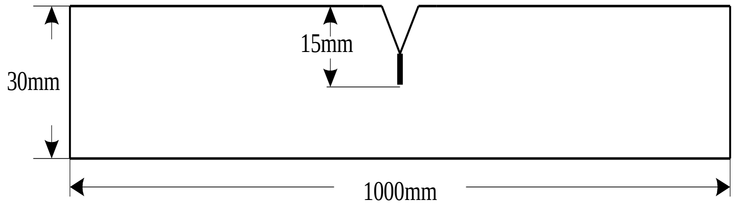

Figure 1. Geometric Parameters of Test Sample

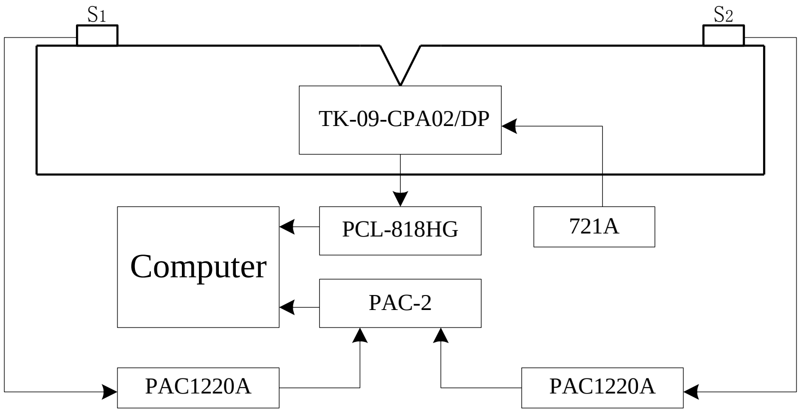

Figure 2. Experimental System Structure

The system structure is in Figure 2 and the detailed meaning of the symbol in Table 1. S1 and S2 are both Acoustic Emission sensors. The purpose of setting two Acoustic Emission sensors is to reduce the error through data processing method.

Table 1. Experimental Instrument Types

Number	Name	Type	Function
1	Analysis system of Acoustic Emission data	MISTRAS	Data analysis
2	Data acquisition card in channel 2	PAC-2	Data acquisition
3	100KHz-300KHz hardware filter	PAC1220A	Prepositive filter and amplification
4	Acoustic Emission sensor	R15	Signal detection
5	Crack detector	TK-09-CPA02/DP	Crack length detection
6	A/D acquisition card	PCL-818HG	Crack length acquisition
7	Regulated power	721A	Power supply for crack detector

The crack detection machine TK-09-CPA02/DP is also adopted the technology of Acoustic Emission detection which used the same couplant with S1 and S2 in fixing. Its crack length measuring range is 0-100mm and output is 0-5V DC voltage. In this experiment, via the calculation formula from the manufacturer, the output 0-5V DC voltage of TK-09-CPA02/DP is corresponding with the crack length of 0-50mm.

In this experiment, be sure of PCA-2 and PCL-818HG are synchronous triggering. We design a RS trigger for this, the input of the RS trigger is loading start -up signal from test-bed, the output is sampling trigger signal of PCA-2 and PCL-818HG.

3. Detection and De-noising of Signal

Take an axle sample and make a 10mm depth notch created by men beforehand. Then make this sample loading vertical gradually till 0.5KN and acquisition signal from the two Acoustic Emission sensors (respectively named S1 and S2) during this process, and then analysis location. In order to simulate actual operation process, the wheelsets are rotating at speed of 250 rpm in the whole test.

Original Acoustic Emission signal from the sensor S1 is shown in Figure 3. The sampling frequency f_s=1.6MHz, take original Acoustic Emission signal into wavelet decomposition with 4 tier. Receiving decomposed frequency band signals are shown in Figure 4 to Figure 8 and the frequency band information labeled after the figure.

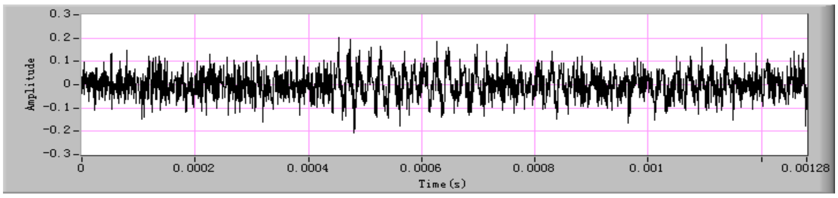

Figure 3. Original Acoustic Emission Signal from the Sensor S1

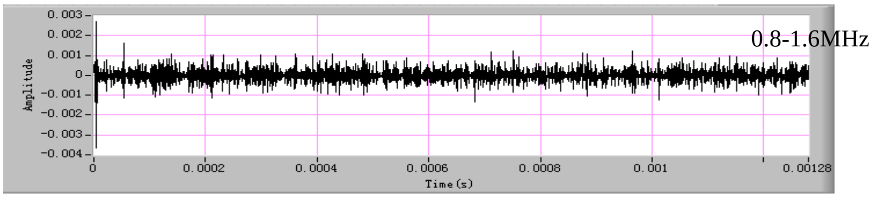

Figure 4. 1 Tier Decomposed High-Frequency Signal of S1

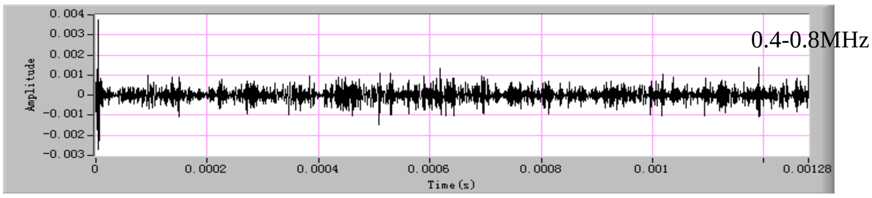

Figure 5. 2 Tier Decomposed High-Frequency Signal of S1

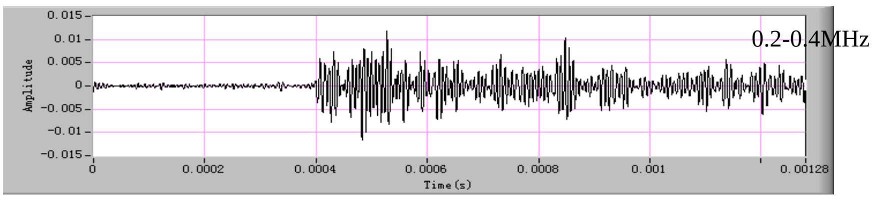

Figure 6. 3 Tier Decomposed High-Frequency Signal of S1

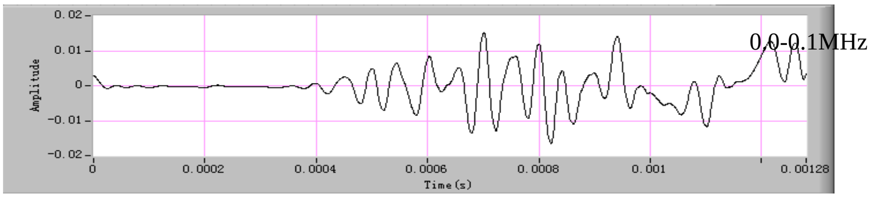

Figure 7. 4 Tier Decomposed Low-Frequency Signal of S1

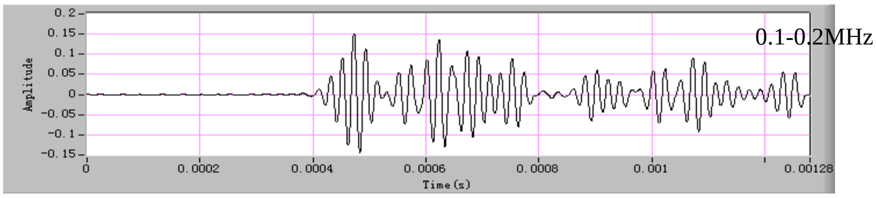

Figure 8. 4 Tier Decomposed High-Frequency Signal of S1

The same de-noising method can achieve denoised signal from sensor S2. Analysis beforehand, take 4 tier decomposition high-frequency signal (100KHz—200KHz) into time difference analysis. Sampling point location has impact on time difference analysis, due to the signal after wavelet de-noising is discrete. In this test, we put 4 tier decomposition high-frequency signal into 8-step Butterworth filtering for overcoming the influence of sampling point location and increasing positioning accuracy, which is signed in Figure 9. Butterworth filtering of the 4 tier decomposition high-frequency signal of the two sensors have the same phase-shifting, so it will not influent the result of time difference analysis.

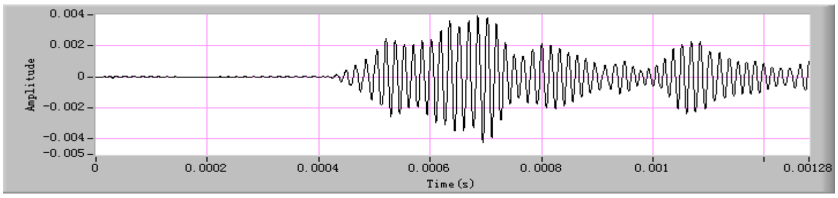

Figure 9. Result of Butterworth Filter with 4 Tier Decomposition High-Frequency Signal

4. Positioning Experiment

This test poses a positioning method that based on the first peak and put it into experimental compare with Gabor wavelet Transformation.

Deal Butterworth filtered 4 tier decomposition high-frequency signal in threshold method for locating point. Threshold value is according to the level of noise, currently 10-20 times higher than noise. However the noise is due to the estimation of the noise in wavelet threshold method. The details are in Figure 10. The first step is to find the first point p0 that signal and threshold value intersecting, which basis for threshold value, second find the forward peak p1 which closest to p0 in reverse direction, finally get the middle point "start" from p0 and p1 as the position point for time difference analysis. The advantage of this action is to avoid value error at fixed point because of jitter of p0.

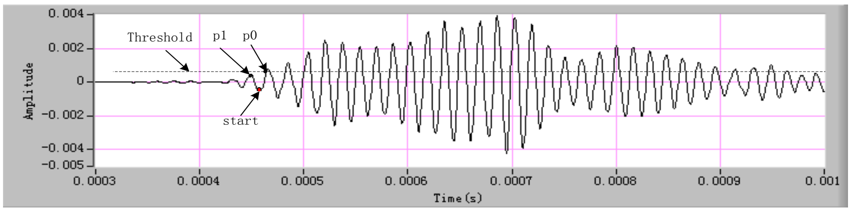

Figure 10. Selecting Position Point with the Result of Butterworth Filter

Gabor wavelet Transformation with continuous frequency:

$$\Psi_g(t) = \frac{1}{\sqrt[\pi]{4}} \sqrt{\frac{\omega_0}{\gamma}} \exp\left[-\frac{(\omega_0/\gamma)^2}{2} t^2 \right] \exp(i\omega t) \tag{1}$$

Fourier transformation is:

$$\Psi_g(\omega) = \frac{1}{\sqrt[\pi]{4}} \sqrt{\frac{\omega_0}{\gamma}} \exp\left[-\frac{(\omega_0/\gamma)^2}{2} (\omega - \omega_0)^2 \right] \tag{2}$$

We can see that, $\Psi_g(\omega)$ gets the extreme value at $\omega = \omega_0$.

Pick up the signal from sensor S1 to Gabor wavelet Transformation, the following Figure11 are three dimensional amplitude time-frequency graph and two dimensional time-frequency contour graph. There are two main peaks in the graph and the second peak value is a little higher than the first one. Gabor wavelet Transformation of signal from sensor S2 getting in the same way is shown in Figure12. It indicates the first peak value is a little higher than the second one. If we locate time difference with the maximum of peak value, the error must be produced and leads to severe mistakes. In this test, we consider that the reason of the error phenomenon is: Acoustic Emission signal is polluted by noise during axle rotary motion at the beginning; secondly many factors such as reflection, refraction, scattering and attenuation of the Acoustic Emission signal affect the corresponding relationship of peaks with different sensors. Judging from the reasons mentioned, we choose the first peak positioning method.

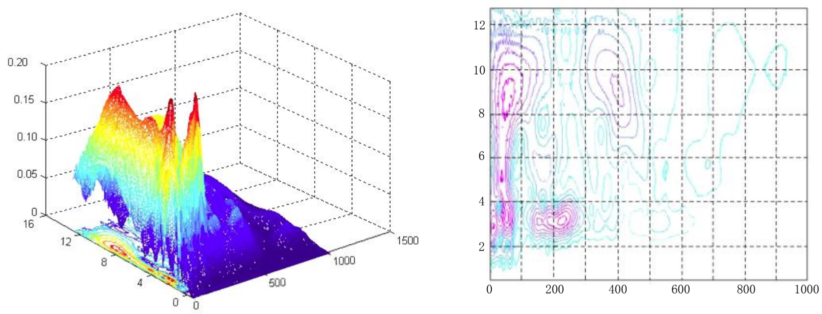

Figure 11. Gabor Wavelet Transformation of Acoustic Emission Signal from S1

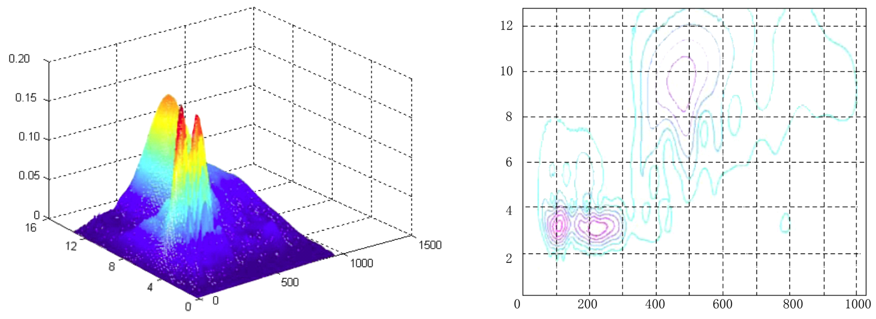

Figure 12. Gabor Wavelet Transformation of Acoustic Emission signal from S2

Regarding sensor S1 as origin, we get four samples 150mm, 300mm, 500mm and 700mm at the position of 10mm depth notch for loading experiment. Figure 13 is the relation graph of the first peak in time difference positioning, its error precision within 5% which accordance with engineering measure demands. The variance $R^2 = 0.9984$ of the fitting curve has already got to the measuring precision that sensor locates. It also reflects propagation velocity of $V = 5095\,m/s$ in Figure13, which close to the typical velocity that frequency band signals propagating in steel. Figure14 is time difference positioning in Gabor Transformation through Acoustic Emission signal maximum peak and reflects propagation velocity of Acoustic Emission signal $V = 4651\,m/s$. We can see that it has a bigger error comparing with the typical velocity t propagating in steels, which is because maximum peak is not stabile. The result of signal's first peak time difference positioning in Gabor Transformation is in Figure15 and the propagation velocity of Acoustic Emission signal is $V = 4987\,m/s$, positioning error and propagation velocity of Acoustic Emission signal are basically the same in Figure13. It also indicates that to use the first peak in time difference positioning is correct and reliable. Propagation velocity of Acoustic Emission signal reflected in this set of data is lower than the velocity reflected in Figure13, that's because there's no reversing optimization process in valuing the first peak in Gabor Transformation.

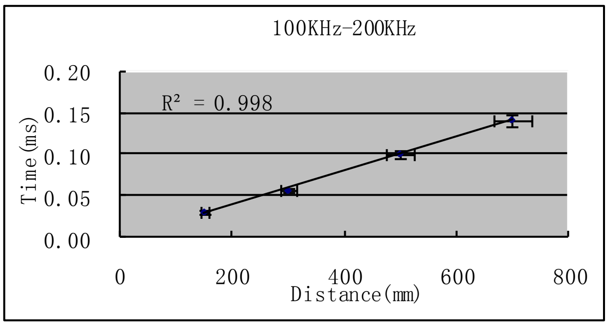

Figure 13. The First Peak in time Difference Positioning of Signal

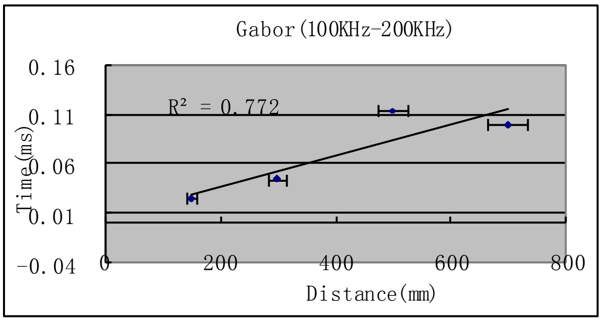

Figure 14. Time Difference Positioning in Gabor Transformation through Acoustic Emission Signal Maximum Peak

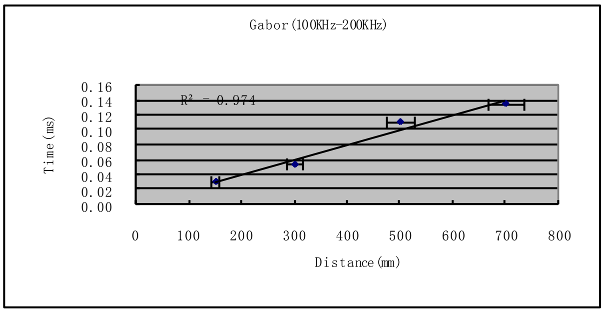

Figure 15. Signal's First Peak Time Difference Positioning in Gabor Transformation

5. Conclusion

Through the above analysis, either the method we mentioned or Gabor Transformation is using time difference positioning to time difference position, and both of them can satisfy the needs of project. But we also see that the method proposed in this paper is better than Gabor transform method in calculation degree and algorithm. Therefore the proposed time positioning method can be used to some real time requirement of high occasions, such as automatic radar target tracking process.

Acoustic emission signal with complex component can decompose the signal relevant to material crack via wavelet transformation under the background of strong noise. It can achieve position detection and fault location for the axle of railway vehicles through the signal. Tread, bearing, wheel of wheelsets have different acoustic emission signal frequency, we can solve the axle of railway vehicles system with different kinds of fault and location based on this method.

6. Acknowledgment

This work supported by the Key Program of National Natural Science Foundation of Heilongjiang No.ZD201309, and Project supported by the Maor International Joint Research Program of China (Grant No. 2014DFB70120).

References

[1] Z. Du, H. He and L. Zhou, "Enhance Applying Administration Of Locomotive Running Gear Monitoring Device", Be Sure Of Operation Safety Of Heavy Haul Speed Raising Locomotive, edited by The Tenth Session Of The Association For Science And Technology Annual Conference Anthology(1), chapter 715, **(2008)**.
[2] Y. Yan, "Control, Monitoring and Diagnosis Technology", edited by Electric Locomotive And Mass Transit Vehicle **(2004)**.
[3] M. Yang and R. Geng, "Acoustic Emission Detection", edited by Beijing Machinery Industry Press, **(2005)**.
[4] Y. Li, C. Huang, H. Li and X. Wang, "Acoustic Emission Signal Detection Of Fatigue Crack", edited by Computer Measurement And Control, **(2004)**.
[5] G. Liu and Q. Cheng, "Technology Of Acoustic Emission And Application In Metal Materials Area", edited by Shanghai Metal, **(2001)**.
[6] C. Jiang, L. Wang, W. You, N. Zhai and M. Chu, "Acoustic Emission Signal De-noising Research Based On Translation Invariant Wavelet", edited by Instrument Journal, **(2006)**.

