Fault Detection System of Axle's Track Based on Virtual Instrument

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Abstract. Railway vehicle is usually working in hazardous environment. The operational status of axle, which is the railway vehicle's main components to run, affects the safe operation of the railway vehicle directly. Over the years, the railway of our country has remained low equipment-rate, high using-rate and high intensity-transport. In addition, because of the need of the rapid development of economy, our country has raised the speed of the railway vehicle, which leads to the railway vehicle's axle wearing and tearing seriously, the life shortened and accidents increasing significantly. So, it is very necessary and urgent to develop the detection system because axle is related to the safety of the railway vehicle. Compared with traditional instrument, the virtual instrument has characteristics of openness, easy using and high cost performance. It has already been widely used in detection systems at present. Based on LabVIEW which is developing platform software of NI Company, the paper has designed a kind of fault diagnosis system on locomotive axle's track.

Keywords: Virtual instrument; fault diagnosis; wavelet analysis; acoustic emission.

1. Introduction

The locomotive running components, such as axles, tires, wheels, wheel bearings and so on, can be easily affected by breaking factors, like cyclic stress, friction, high and low temperature etc. The damage phenomena of their abrasion, cracks, peeling off are very common. Safety of railway transportation is in severe test[1]. In response to the status quo, the fault diagnosis system developed by virtual instrument can realize fast and reliable fault detection if it can be applied to detection line of locomotive running components.

Virtual Instrument represents development direction of electronic measuring & control equipment. In comparison with traditional electronic instruments, virtual instrument has many advantages in multipurpose, data-processing ability, high automation degree, easy system expansion and networking. In this paper, LabVIEW is used as a development platform and adopts G language on system design. In comparison with traditional language, G is easier to use and understand. Furthermore, it provides a large number of library functions and drivers which can be directly called in modular way by users, so users' applications can be set up easily and quickly. Accordingly, the development cycle is significantly shortened and development costs are saved.

2. Acoustic emission and wavelet analysis

2.1 Acoustic Emission Technology[2]

When the phenomena made by the external force, such as the plastic deformation, the internal lattice mismatch and the grain boundary sliding or when the cracks grow and fracture as well as other defects format and grow, energy will be burst released in the form of elastic wave. The phenomenon is known as acoustic emission (AE). Because the elastic wave of acoustic emission can reflect some properties of materials, so acoustic emission signal detection is used. It can determine a certain status of materials or equipment, that is, acoustic emission monitoring. Acoustic emission monitoring is a dynamic non-destructive detection method. It is different from other non-destructive detection method. Acoustic emission signals are occurred under the external condition, it has high degree of

sensitivity towards to defect change. Acoustic emission monitoring can detect micro-crack change at the magnitude of micron. As Shown in Fig. 1.

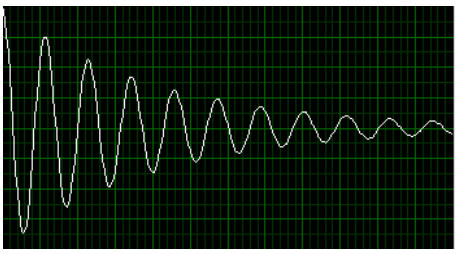


Fig.1 Data collected by acoustic emission sensor

In addition, because the vast majority of materials have characteristics of acoustic emission, acoustic emission detection is not limited by material. It can continuously take a long-term monitor on safety and overrun alarm. It is the place which is superior to other non-destructive detection. However, most of acoustic emission is very weak and cannot be heard directly. So the signal must be detected by sensitive electronic equipment.

2.2 Wavelet Analysis Theory and Application[3]

Wavelet transform is to add an enabled condition for window function on the basic of window Fourier transform. It makes window to be automatically adjusted to be narrow when in condition of high frequency and to be widened in condition of low frequency. Such characteristics make wavelet transform has the adaptability to signal.

Enabled condition:

$$C_{\varphi} = \int_{-\infty}^{\infty} |\omega|^{-1} |\varphi(\omega)|^2 \, d\omega < +\infty \tag{1}$$

Or

$$\int_{-\infty}^{\infty} \varphi(x)dx = 0 \tag{2}$$

The function $\varphi(x)$ which can satisfy the condition is called the basic wavelet or mother wavelet function.

The function

$$\varphi_{a,b}(x) = 1/\sqrt{a}\varphi(\frac{x-b}{a}) \tag{3}$$

Transformed from the Mother Wavelet Function $\varphi(x)$ by translation and companding, is called continuous wavelet transform made by $\varphi(x)$.

$$f(x) \in L^2(R) \tag{4}$$

makes wavelet transform to $f(x)$,it is defined as

$$(w_{\varphi} f)(a,b) = |a|^{-1/2} \int_{-\infty}^{\infty} f(x)\overline{\varphi(\frac{x-b}{a})}dx \tag{5}$$

In practice, frequency axis is usually need to be divided into some adjacent frequency bands, as continuous wavelet transform is inconvenient in the actual numerical calculation , so the continuous wavelet must be discretization.

Make $\varphi(x) \in L^2(R)$ (6)

So the discrete wavelet transform is defined as:

$$\varphi_{b_0,k,j}(x) = 2^{k/2}\varphi(2^k x - jb_0) \tag{7}$$

Assume that the scale equation and wavelet equation are as follows:

$$\phi(x) = \sqrt{2}\sum_{n\in z} h_n \phi(2x-n) \tag{8}$$

$$\varphi(x) = \sqrt{2}\sum_{n\in z} g_n \phi(2x-n) \tag{9}$$

Set the multi-resolution analysis of $L^2(R)$ for$|V_j: j \in Z|$, W_j is the orthogonal complement space of space V_j in space V_{j+1}. According to the definition of wavelet transform, the signal $f(x)$ can be wavelet series. The orthogonal projection of $f(x)$ in the closed subspace V_j and W_j can be marked as $f_j(x)$ and $g_j(x)$.

$$f_j(x) = \sum_{k \in z} c_{j,k} \phi_{j,k}(x) \tag{10}$$

Then

$$g_j(x) = \sum_{k \in z} d_{j,k} \varphi_{j,k}(x) \tag{11}$$

According to the relationship of space orthogonal and decomposition $V_{j+1} = V_j \oplus W_j$, we can get:

$$f_{j+1}(x) = f_j(x) + g_j(x) \tag{12}$$

It shows that the wavelet transform is to decompose the signals into wavelet combination. The local characteristics of the signals can be observed by selecting the appropriate wavelet function and signal deep processing can be realized.

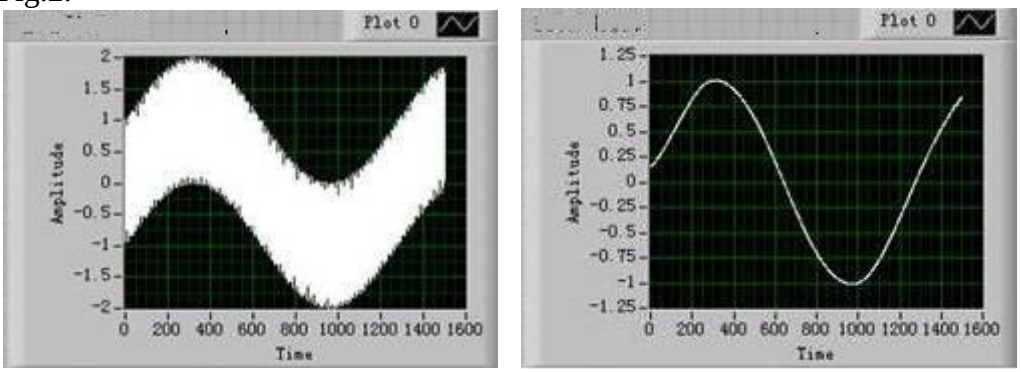
Wavelet transform can be realized by Mallat tower fast algorithm[4], that is, a set of band-pass filter is used for filtering signals and thus the signal is decomposed into different frequency components of channel. Wavelet transform fast algorithm is commonly expressed as:

$$C_{j,n} = \sum_{m \in z} \overline{h_{m-2n}} C_{j+1,m} \tag{13}$$

$$D_{j,n} = \sum_{m \in z} \overline{g_{m-2n}} C_{j+1,m} \tag{14}$$

The signals can be decomposed into different frequency channels by using wavelet transform in range of the frequency analysis then make frequency localization of the signals. The signals in the channel frequency which contains the failure information of equipment can be analyzed to extract signal features and then make fault identification and diagnostics.

MATLAB Script toolbox of Labview[5] provides many functions of wavelet analysis. Using of these functions, Labview can analyze not only time-domain signal but also analyze frequency domain signal at the same time. Wavelet analysis needs not complex programs by using Labview. It can be realized by using simple program and only the corresponding required function should be set. As Shown in Fig.2.



(a) Before the waveform extraction (b) After the waveform extraction

Fig.2 Virtual wavelet signal extraction front panel

3. System design

Using wavelet analysis technology, the system can realize the locomotive axle's fault detection. The status data of locomotive axle can be obtained by acoustic emission sensors. Then make the corresponding filtering and amplification of the data. Finally the data is sent to PC machine through the data acquisition card to make corresponding data-processing and get the diagnostic report. The system mainly includes two parts of hardware and software. The hardware can realize the functions of

data pre-processing, data acquisition, data storage and data transmission; the software can realize data analysis, processing, display, print and other functions. As shown in Fig. 3.

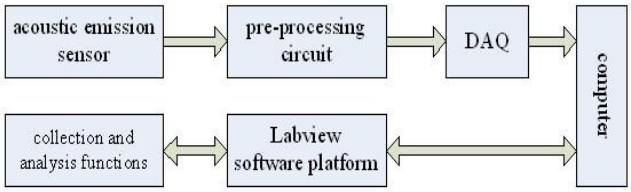


Fig.3 System Structure Diagram

4. Software structure

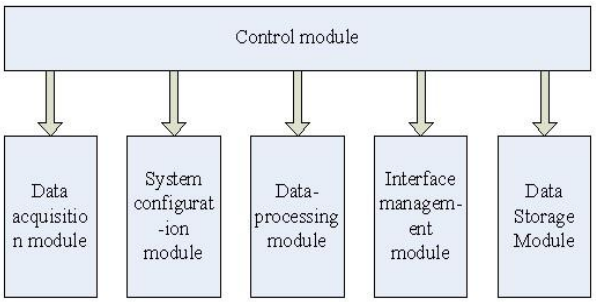


Fig. 4 Overall software structure

4.1 Control Module

Control module is framework of the whole diagnostic application and also provides a way to the users to enter the functional modules. Each functional module communicates with the main control module through its input and output ports to obtain the corresponding instruction or data and completes their specific functions.

4.2 System Configuration Module

System configuration module completes the settings of hardware, constant, file parameters which are related to the system, including analog input channel configuration, sampling frequency parameter setting, file storage path setting and etc.

4.3 Data Acquisition Module

Data acquisition module completes the acquisition of various measured parameters. The data collected by data acquisition module is sent to control module which sends the data to data-processing module to be processed. At the same time, it will be also sent to interface management module for real-time waveform and parameter display.

AI Config.vi module is used to configure DAQ equipment and set the cache size. In the way of the data acquisition module it will keep the signal collection as long as the data acquisition function of the DAQ device is launched. And the collected data is sent to FIFO buffer. Through this approach it can realize the long time signal acquisition without losing signal.

4.4 Data-processing Module

Data-processing module is the core of the system software. It is mainly to complete the acquisition of data processing and extract useful information of locomotive axle fault diagnosis. Based on these results to determine fault diagnosis and bring the results back to the main control module.

The malfunction of locomotive axle during operation can be divided into two categories according to the characteristics of vibration signals: one is abrasion failure, the other is surface damage class failure. Vibration signal produced by abrasion fault has the same characteristics with the normal vibration signal of its axle. There is no other difference in abrasion fault vibration signal in addition to vibration levels higher than normal. So by measuring the maximum peak then compared with normal values, the paper can determine whether the axle is in abrasion fault state. Surface damage fault is the major fault type in the diagnosis. Wavelet analysis has the characteristic of analyzing time and frequency domain simultaneously. Wavelet packet technique[6] can orthogonal decompose the signal to independent frequency band. The wavelet packet analysis technology is used, which is in

Labview's Script node, to decompose the detecting signal. The signal which has the fault characteristics is reconstructed. Through the demodulation of Hilbert transform[7] we can get signal envelope and then calculate the failure frequency points. The damage position can be found by the location of frequency fault point.

4.4 Interface Management Module

A good man-machine interface[8] is established to make users to process the case with ease though they do not understand the specific implementation of each function module. Specific function can be achieved as: achievement of man-machine interactive operation; the waveform display of signal time domain and frequency domain analysis; the real time display of characteristic parameters; alarm visualization.

5. Conclusion

The diagnostic system uses NI LabVIEW software platform and makes full use of PC-powerful hardware resources to use software instead of hardware by the greatest extent. The system can realize the goals of easy operation, powerful and cost-effective. The result of location experiment shows that the time difference method based on wavelet transform and the first wave peak can enhance the precision of locating AE signals obviously. Virtual instrument has broad application prospects in measurement and control system.

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