Research on Fault Diagnosis System of Freight Train Bearings Based on Virtual Instrument

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Abstract. Based on the analysis of the fault mechanism and the characteristics of the vibration signal, a fault diagnosis system of the freight train bearing based on virtual instrument is built on the theoretical research. The hardware selection and software programming are described in detail. The validity of the system is validated by the diagnosis of an outer ring fault bearing by the wheel test. The research shows that the system can detect the bearing fault of the freight train effectively and quickly, and can display and store all kinds of parameter values and test results in real time, thus improving the fault diagnosis efficiency of freight trains.

Introduction

At the same time, the rapid development of the railway, train the key components of the process of health protection has become a difficult task. In the current train operation and maintenance work, manual maintenance is still the main work, some of the existing diagnostic equipment is still a low degree of automation, diagnostic accuracy, diagnostic efficiency is low. In order to prevent the train running in the process of security risks, maintenance, maintenance of the concept of the more the better, resulting in a huge time, manpower, money wasted, while too many dismantling also affect the life of the parts. Particularly, some precision and fragile components, such as bearings, which play a key role in the operation of the train, have suffered from such faults as fatigue, wear and crack due to their long-term high speed and high load, and even occur burning shaft, cutting axis and other major safety incidents. According to statistics, in the course of normal operation of the train, because the key components such as bearings, gears and other failures accounted for more than 65%, train bearing failures caused by railway operation accidents accounted for 1/3 [1]. In order to ensure the safety of train operation and reduce the cost of maintenance and repair, we should not only improve the reliability of key components of train, but also develop, develop and perfect the monitoring system which can identify, alarm and diagnose faults. As the basis of the "condition-based maintenance".

In this paper, a highly efficient, stable and reliable vibration measurement system is designed based on the virtual instrument widely used in test and measurement field. The hardware composition and software realization of the system are described in detail. Finally, an example of train bearing fault diagnosis is verified. The feasibility of the system. By modifying the data acquisition parameters and the threshold, the system can be applied to different types of bearings to assess the health status.

Vibration Mechanism and Fault Characteristics of Train Bearings

Rolling bearing is composed of inner ring, outer ring, rolling element and cage. Under normal circumstances the outer ring does not move, the inner ring with the shaft rotation. Rolling bearings in the work, due to its structural features, manufacturing errors and operational failures and other internal factors, and other parts of the drive shaft and the role of power and other external factors, so that the rolling bearing and housing or chassis system In the course of operation vibration, resulting in transient alternating excitation force [2,3]. Train bearing in a long-term high-load, high-speed operating environment, and often poor installation accuracy, poor lubrication, and even dust mixed,
electric shock and other extreme situations. Therefore, the train bearing failure in the harsh conditions of frequent, the vast majority occurred in the inner ring, outer ring, the rest occurred in the rolling body [4,5]. When the inner ring, outer ring, rolling body pitting or peeling, such as failure, will have a characteristic frequency of the impact caused by bearing vibration, rolling bearing fault vibration frequency mainly consider the following aspects [6]

(1) inner ring fault characteristic frequency:

\[
\frac{nz}{120} \left(1 + \frac{d}{D} \cos \alpha \right)
\]

(2) outer ring fault characteristic frequency:

\[
\frac{nz}{120} \left(1 - \frac{d}{D} \cos \alpha \right)
\]

(3) Rolling body fault characteristic frequency;

\[
\frac{n}{120} \frac{D}{d} \left(1 - \frac{d^2}{D^2 \cos^2 \alpha} \right)
\]

(4) cage pass frequency;

\[
\frac{n}{120} \left(1 - \frac{d}{D} \cos \alpha \right)
\]

Where \( n \) is the number of revolutions per minute, \( z \) is the number of rolling elements, \( d \) is the rolling element diameter, \( D \) is the average diameter of the bearing, and \( \alpha \) is the contact angle.

**Design and Realization of Train Bearing Fault Diagnosis System**

The main function structure of the system is shown in Fig.1. The main function structure of the system is shown in Fig.1. The main functions of the system are shown in Fig.1., Vibration acceleration sensor with a conditioning circuit with the acquisition device will be vibration acceleration signal in the form of digital signals into the computer, the vibration signal collected in the form of graphics, while the signal can also be real-time storage. Users will be the physical parameters of the bearing input to the computer, you can analyze the vibration signal, and then bearing the fault diagnosis.

**System Hardware Components**

The National Instruments (NI) Co., Ltd. NI Compact DAQ9172 data acquisition chassis and NI-9234 data acquisition module signal conditioning and data acquisition system, as shown in Figure 2. NI-9234 is a 4-channel vibration signal acquisition module for high-precision measurement of IEPE sensors. NI Compact DAQ provides simple plug-and-play connectivity with USB for easy field measurement of electronic applications. CA-YD-188 Piezoelectric Acceleration Sensor, which is produced by Jiangsu Lianneng Electronic Technology Co., Ltd., can be directly connected with NI-9234 acquisition card. In actual use, the sensor is fixed by magnetic seat.
System Software Design

The software part of the system is realized by LabVIEW2012 programming, including data acquisition and storage module, bearing characteristic frequency calculation module, time domain analysis module, frequency domain analysis module and time frequency analysis module.

(1) Data acquisition and storage module

Data acquisition and storage module using DAQ Assistant in LabVIEW for each data acquisition channel sensor type, sensor sensitivity, measurement range, sampling frequency and other parameters set. Using the producer-consumer architecture to isolate the data collection and data storage links to improve program execution efficiency, as shown in Figure 4. In the storage session to the data stored in decimal as a spreadsheet-type txt documents, stored using the "format date / time string" vi the file name according to the current date and time named "month - day - hours - minutes" format To achieve full automation.

(2) Bearing characteristic frequency calculation module

The module is divided into two parts, the first part for the user to input the physical parameters of
the bearing, the second part is used to display the system automatically calculate the location of damage to the bearing vibration signal characteristic frequency. The calculated characteristic frequency can be used to judge the frequency domain analysis result.

(3) Time domain analysis module

The module includes filtering and time domain statistical functions, the front panel shown in Figure 6. Users can operate the front panel controls for filter selection and parameter settings, and through the waveform in real-time observation of the filtered waveform. At the same time, the system can also quickly measure the maximum, minimum, peak-to-peak, mean, variance, mean square, square root amplitude, mean amplitude, mean square amplitude and kurtosis, waveform index, Pulse index, margin index and other non-dimensional indicators for rapid calculation. In order to make the calculation process fast, the programming adopts the way of full parallelization, and fully utilizes the computing power of multi-core and multi-thread computer central processing unit.

(4) Frequency domain analysis module

Frequency domain analysis of the main part of the resonance demodulation technology, based on user-selectable band-pass filter parameters. The module uses Hilbert transform to complete the envelope, and then obtain the power spectrum to obtain the spectrum, the program shown in Figure 7.
(5) Time-frequency analysis module

Time-frequency analysis part of the main use of Hilbert Huang transform method, the core steps to find the IMF process shown in Figure 8. The EMD program is written according to this flow.

![Diagram](image)

**Figure 8.** For the IMF process.

**Train Bearing Fault Diagnosis Test Study**

Test using a vehicle bearing train running machine, as shown in Figure 9. The vibration signal of the double-row tapered roller bearing of 197726 is taken as the analysis object. The main parameters are shown in Table 1. Before the test, a normal bearing and a fault bearing are transferred to the bearing pressing machine, then the conventional running joint is run on the running machine. At the same time, the vibration signal of the fault bearing is collected and analyzed.
Figure 9. Train bearing running machine.

Table 1. 197726 bearing the main parameters.

| Bearing average diameter D/mm | Roller diameter d/mm | Contact angle α | Number of rollers / Each |
|-------------------------------|----------------------|-----------------|-------------------------|
| 176.29                        | 24.74                | 8.833           | 20                      |

According to the analysis of Section 2, we can calculate the characteristic frequency of a typical fault at the speed of 469 r/min, as shown in Table 2.

Table 2. Bearing typical failure characteristic frequency Hz.

| Outer ring failure | Inner ring failure | Roller failure | Cage failure |
|--------------------|--------------------|----------------|--------------|
| 67.3               | 89                 | 54.6           | 3.4          |

**Normal Bearing Diagnostic Test**

The time-domain analysis module of this system is used to analyze the vibration signals of a normal bearing and select the representative characteristic indexes, as shown in Table 3.

Table 3. Normal bearing vibration signal time domain analysis results.

| Kurtosis | Waveform index | Peak | Pulse index | Margin |
|----------|----------------|------|-------------|--------|
| 0.116    | 1.258          | 5.839| 7.348       | 3.123  |

**Outer Ring Fault Diagnosis Test**

Select an outer bearing fault test strip stripping, as shown in Figure 10.

Figure 10. Outer ring peeling fault bearing.

Using the system of vibration signal acquisition, the time domain waveform shown in Figure 11.
Figure 11. Time-domain waveform of vibration acceleration signal of outer ring failure bearing.

The time domain index of statistical analysis, the results shown in Table 4.

| Kurtosis | waveform index | peak   | pulse index | margin |
|----------|----------------|--------|-------------|--------|
| 3.234    | 1.261          | 4.787  | 6.035       | 6.944  |

It can be seen from the analysis, compared with the normal bearing test, the kurtosis and the margin index of the outer-ring failure test have been obviously increased, but the waveform index, peak value and pulse index have not changed greatly. But through the above conclusions can be initially concluded that the existence of bearing damage.

The signal is analyzed in frequency domain using the resonance demodulation method, and the envelope spectrum is obtained as shown in Fig. Figure 7.5Hz frequency, 66.9Hz at the failure of the characteristic frequency and its order of frequency is clearly visible, so you can determine the existence of the bearing outer ring damage.

Figure 12. Envelope spectrum of vibration acceleration signal of outer ring failure bearing.

The first three IMF components obtained by EMD decomposition of the 0 ~ 1s vibration signal are shown in Fig.

(a) decomposition of the outer ring fault bearing vibration acceleration signal to get the first IMF component

Figure 13. decomposition of the outer ring bearing vibration acceleration signal to get the first three IMF components.
(b) Decomposition of the outer ring fault bearing vibration acceleration signal to the second IMF component

(c) Decomposition of the outer ring fault bearing vibration acceleration signal to the third IMF component

After HHT analysis shown in Figure 14 time-frequency distribution, can be seen from the figure has a clear impact of periodic components.

Figure 14. Time-frequency analysis diagram of vibration acceleration signal of bearing with outer ring failure.

Conclusion

Through the above experimental research, it is shown that using LabVIEW software and Compact DAQ, which is a portable data acquisition device, is used to diagnose the bearing fault of the freight train. The vibration signal of the outer ring bearing is analyzed by the resonance demodulation method and the HHT Spectrum analysis, diagnosis is obvious. This system is stable and efficient, can effectively diagnose the fault of the freight train bearing. (Jiangxi Education Fund Key Project: Research on State Identification and Accuracy Measurement and Control of Complex Manufacturing System, Item Number: GJJ171039)

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