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Fault diagnosis system of rotating machinery vibration signal

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Abstract

A high demand has been presented in the measuring and diagnosis of vibration signal of rotating machinery, which can reflect the running state information of rotating machinery equipment. This paper designs a new type of fault diagnosis system of rotating machinery vibration signal, which can measure the vibration acceleration and velocity signals accurately, and analyze the vibration severity and frequency division amplitude spectrum of vibration signal. Experiment showed that our system can diagnose typical mechanical fault.

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Keywords: Rotating machinery; Vibration severity; Frequency division amplitude spectrum; Fault diagnosis

1. Introduction

Rotating machinery has been widely used in the area of chemical industry, aviation, and power. It generates vibration signal which contains the working state information of mechanical equipment. Vibration of rotating machinery has many disadvantages, which result in serious consequences without timely processing[1]. The aim of fault diagnosis system of rotating machinery vibration signal is mainly to study the change rule of dynamic characteristic and the recognition in the running process of rotating machinery. By this kind of analysis, some faults can be found in time to make the rotating machinery system operation reliable and efficient.

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Many scholars proposed many fault diagnosis approaches to vibration signal. XIANG Ling proposed a joint time-frequency analysis approach to vibration signal[2]. She took rotor failure as the research object, and studied the common approach to time-frequency analysis, but the analysis of vibration severity was lacked. In document[3], the vibration signal was acquired through the high-speed data acquisition card and then the spectrum was analyzed, but its sampling accuracy was lower, so the spectrum refining analysis was limited. Because of the above problems, we propose a new fault diagnosis system of rotating machinery vibration signal, which combined Field-Programmable gate array(FPGA), PCI extensions for the instrumentation (PXI)[4], and time-frequency domain algorithms with virtual instrument technology.

The system can transmit the vibration signal in real-time mode, and achieve high measure accuracy(0.05%). High precision can make vibration signal more accurate in frequency domain analysis. Moreover, we combine vibration severity and frequency spectrum analysis to reflect malfunction omen from different features so that we can diagnosis the fault reasons timely and more accurately.

2. System architecture

The fault diagnosis system includes the vibration accelerometer, velocity sensor, signal conditioning module, PXI data acquisition system, application software and database system. Fig.1 shows the architecture. The rotating machinery generates vibration signal, and the system collects these signals with vibration accelerometer and velocity sensor installed on the rotating machinery[5]. First, the A/D (Analog/Digital) data acquisition system turn the vibration acceleration signal and velocity signal into digital signal. Then, the computer read the digital data through PXI bus interface. Application software would make time and frequency domain analysis for vibration signal and extract the fault characteristic information of vibration signal. Because the characteristic frequency of rotating machinery fault vibration is related to the fundamental frequency of the rotor, we can obtain the fault reason through the characteristic value of amplitude spectrum of frequency division[6-8]. With diagnosis results, the operator can solve the hidden dangers, and assure the normal operation of equipment.

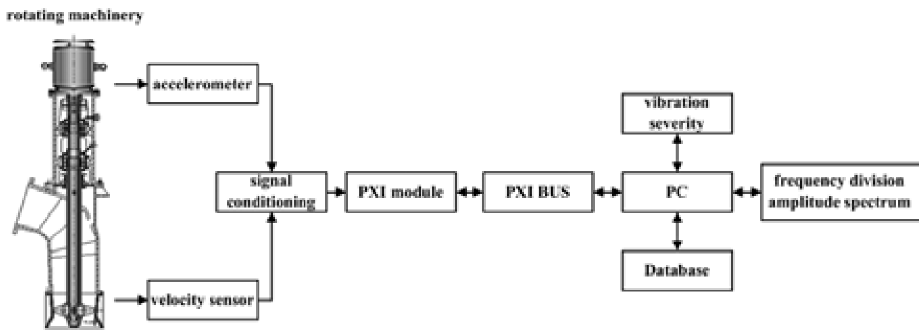

Fig. 1. System architecture

3. Analysis approach of vibration signal

3.1. Vibration severity

The vibration severity is the general characteristic value describing the mechanical vibration level at home and abroad. It can be computed with vibration energy. By comparing severity calculation result and severity reference standard, we can obtain the operation state of the equipment. Vibration severity is completed through the RMS (Root-mean-squared) calculation of vibration velocity.

$$v_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)dt} = \sqrt{\frac{1}{2}(v_1^2 + v_2^2 + v_3^2 + ... + v_n^2)} \tag{1}$$

3.2. Frequency division amplitude spectrum

Frequency division amplitude spectrum is the Fourier transform of vibration acceleration signal. When fault happened, the relevant characteristic frequency amplitude value of acceleration will change.

The discrete Fourier transform(DFT) of limited sequence X(i) is defined as follows:

$$X(i) = \sum_{n=0}^{M-1} x(m) W_M^{mi} \tag{2}$$

$$where, \text{i} = 0,1,2,...\text{M-1}, W_M = e^{-j\frac{2\pi}{M}}, j = \sqrt{-1}$$

The DFT requires many multiplications and additions. In the system, we use the split-radix FFT. It divides the output item into two groups according to the parity, and uses radix-2 FFT for even sequence, radix-4 FFT for others. Thus, the complexity of calculation is reduced greatly, and reduces the computing time[9,10].

$$X(2s) = \sum_{m=0}^{\frac{M}{2}} \left[x(m) + x(m + \frac{M}{2}) \right] W_{\frac{M}{2}}^{ms}, \quad where, s = 0,1,2...,\frac{M}{2} - 1 \tag{3}$$

$$X(4s+1) = \sum_{m=0}^{\frac{M}{4}-1} \left[\left(x(m) - x(m + \frac{M}{2}) \right) - j \left(x(m + \frac{M}{4}) - x(m + 3\frac{M}{4}) \right) \right] W_M^m W_{\frac{M}{4}}^{ms} \tag{4}$$

$$X(4s+3) = \sum_{m=0}^{\frac{M}{4}-1} \left[\left(x(m) - x(m + \frac{M}{2}) \right) + j \left(x(m + \frac{M}{4}) - x(m + 3\frac{M}{4}) \right) \right] W_M^{3m} W_{\frac{M}{4}}^{ms} \tag{5}$$

$$where, s = 0,1,2...,\frac{M}{4} - 1; \; j = \sqrt{-1}$$

In computing the spectrum amplitude of frequency division, single-sided spectrum is adopted, as is shown in the following formula:

$$A_m = 2 * \left| \frac{FFT(X)}{M} \right| \tag{6}$$

Through the spectrum amplitude of frequency division, the corresponding acceleration amplitude value of various frequency divisions can be found.

4. The implementation of fault diagnosis system

The fault diagnosis system of rotating machinery vibration signal includes three subsystems, the sensor system, measurement system, and software system. The sensor system, the key of the whole system, affects the collection of the vibration signals of rotating machinery, and the data analysis and processing results. The accelerometer and velocity sensor are used in the system. The sensors can transform mechanical energy signal into electric energy signal. The sensitivity of accelerometer is $1.0pC/ms^{-2}$, the sensitivity of velocity sensor is 5.7mV/mm/s. The measurement system is designed based on PXI bus interface. PXI1215 is the important module of the measuring system, and it is a parallel data acquisition module. The highest real-time sampling rate of PXI1215 is 100 KHz, A/D resolution is 16bit. The module consists of analog circuit unit and digital circuit unit. The software system of rotating machinery test platform is composed by virtual instrument software architecture(VISA), device drivers, and application program. Application program completed the data analysis and processing of vibration acceleration and velocity.

5. Experimental results and analysis

We used simulation to evaluate the system. We used the axial flow pump with a $900m^3/h$ flow, 2.5m lift and 960r/min rotational velocity, which was typical rotating machinery. We collected the normal data and fault data, respectively.

Table 1. Vibration severity of various states

State	Vibration severity(mm/s)
Normal	1.05
Minor	1.52
Moderate	2.55
Severe	6.12

From Tab. 1, it can be seen that the value of vibration severity is increasing as the vibration escalates. Vibration severity and vibration trend are consistent. While the vibration severity value in 2.55 mm/s ~ 6.12 mm/s implies that it is dangerous to operate the equipment and should stop running it right now and repair it.

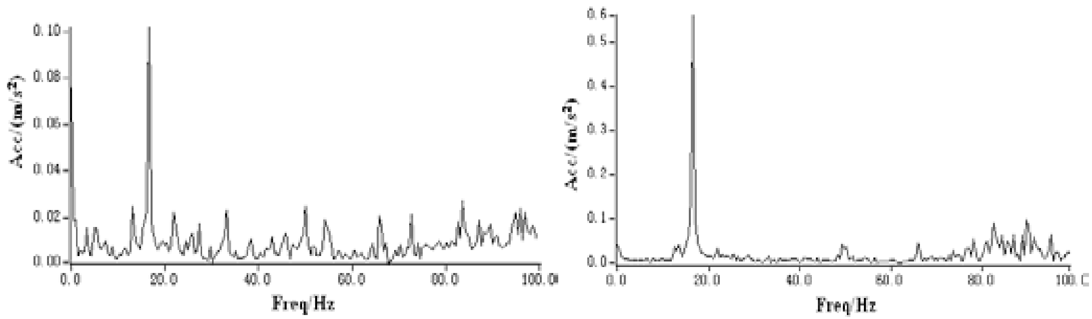

Fig. 2. Frequency division amplitude spectrum of vibration acceleration (a) normal operation; (b) rotor imbalance

When the fault of rotor imbalance happened, the imbalance vibration frequency is the fundamental frequency 16Hz. Thus, the amplitude value in characteristic fault frequency intensifies to $0.60m/s^2$. From the Fig. 2, we can conclude that the energy of vibration at the point of fundamental frequency is the strongest when the imbalance fault of rotor appears. The characteristic frequency of vibration fault caused by imbalance is the same as the fundamental frequency and this conclusion conforms to the characteristic of rotor imbalance vibration.

6. Conclusion

In this paper, a new fault diagnosis system of rotating machinery vibration signal, which can improve the precision of testing vibration signal, was proposed. We used the advanced PXI test platform, adopting 16bit resolution A/D device and FPGA technology in the design. The conditions for further realization of detail analysis of time-frequency domain were also provided. The system can monitor vibration acceleration and velocity signal, making accurate judgment on mechanical fault. Compared with the existed fault diagnosis systems, the system mentioned in this paper can achieve higher accuracy, and improve accurate diagnostic capability and dramatically increased interaction. Experimental results demonstrated that the system had met the design requirements.

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