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Research Article

Rotor Fault Diagnosis and Simulation Based on LabVIEW

Hong-Xin Zhang, Hao Zhou, Xin-Ping Guo and Yu Yan
School of Mechanical and Power Engineering, Harbin University of Science and Technology, Heilongjiang, China

Abstract: A fault diagnosis system based on LabVIEW is researched to analyze the rotating machinery fault. By developing data acquisition, signal analysis, processing and simulation, pattern recognition and fault diagnosis modules, this system can automatically measure and identify the shaft orbit of a rotor and get fault results. A pattern recognition method on the basis of the invariant moment algorithm is studied with LabVIEW and used to recognize shaft orbit shapes. The experimental results show that the shaft orbit of a rotor can be identified through invariant moment calculation. Because the shape of the shaft orbit of the rotor is close to the ellipse the main fault is imbalance. The fault result is proved to be correct by spectrum analysis. This study is helpful to develop a online fault diagnosis system based on LabVIEW.

Keywords: Fault diagnosis, LabVIEW, pattern recognition, shaft orbits

INTRODUCTION

Rotors are the core elements of the rotating machinery. When a kind of machine fault occurs the shaft orbit of a rotor often contain some fault information. Specifically, the shapes and feature of shaft orbits are corresponding to some fault phenomena on a certain extent. So the fault information of a rotor can be extracted by the measurement and analysis of the shaft orbits.

It is very important to research the method of the rotor fault diagnosis and build a system of the fault diagnosis of the rotating machine. The virture instrument technology is used for fault diagnosis has become a hot research. The system of data acquisition and signal analysis based on LabVIEW software has been used to the fault diagnosis research of the rotating machine. (Wang *et al*., 2007; Luo *et al*., 2008; Zhang *et al*., 2005). LabVIEW is a kind of graphical programming software developed by the United States NI (National Instruments) company. LabVIEW has been an important developing tool of virtual instruments due to its powerful capability of data acquisition and signal analysis (Jime′neza and De Frutos, 2005; Qin and Tang, 2002). So LabVIEW software can be fully applied in online diagnosis of the fault information of mechanical systems independently. The further development and application of LabVIEW software in the fault diagnosis of rotating machinery is great significant.

This study is about the research of the rotor fault diagnosis and simulation system based on LabVIEW. A hardware system is built including a flexible rotor test bench and a data acquisition system. Some LabVIEW software modules are developed and integrated, such as the simulation of the shaft orbits and rotor faults, data acquisition, pattern recognition and fault diagnosis modules. This makes it possible for the research of online fault diagnosis of rotating machines based on LabVIEW hardware and software.

SHAFT ORBITS MEASUREMENT SYSTEM

In order to obtain the vibration signals of the rotating machine, a flexible rotor test bench is built including an adjustable speed AC motor (range from 0 to 12,000rev/min), couplings, a flexible rotor, an eccentric disc, bearings, base and sensor bracket. On the other hand, a measurement system based on LabVIEW data acquisition card is set up, which is made of eddy current sensors, pre-amplifiers, low-pass filters and a NI data acquisition card "DAQ-PCI-6251" , as shown in Fig. 1.

The shaft orbits is measured by the LabVIEW data acquisition and analysis module, the module has some functions, such as dual-channel data acquisition, waveform display, digital filtering and synthesis of shaft orbits. The module can be developed by DAQ Assistant of LabVIEW 8.5 version. The programming steps are as follows: setting some parameters including the signal type, sampling rate, sampling number and sampling method in a new DAQ Assistant task; transforming the task into a sub VI to generate a graphical code; and adding digital filtering VI,

Corresponding Author: Hong-Xin Zhang, School of Mechanical and Power Engineering, Harbin University of Science and Technology, Heilongjiang, China

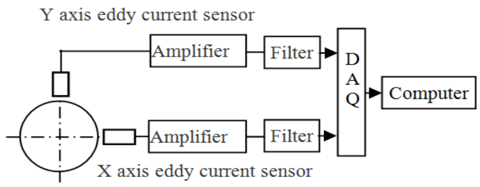

Fig. 1: Block diagram of shaft orbits measurement system

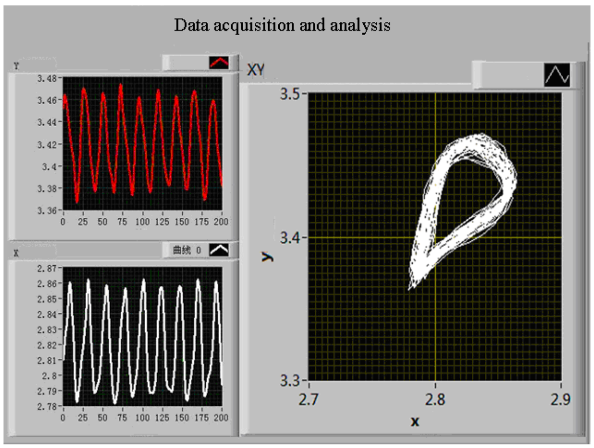

Fig. 2: Control panel of the data acquisition and analysis module

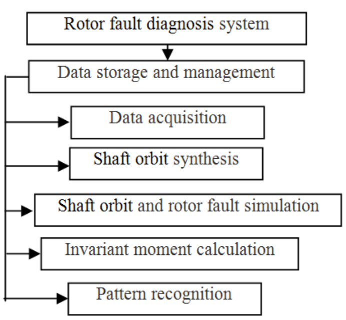

Fig. 3: Block diagram of LabVIEW modules

spectrum analysis VI, writing measurement files VI, graphics display VI and then integrating them into a program.

The control panel of the data acquisition and analysis module is show in Fig. 2. X, Y two-way signals are real-time displayed on the graphic window and the noise has been basically eliminated by using the analog lowpass filter and digital filter. the single-channel signal is similar to a sine wave and the synthesized shaft orbit shape is close to a ellipse.

The measurement of shaft orbits is only the first step of the fault diagnosis. The fault diagnosis system consists of several modules to achieve measurement, simulation, calculation and analysis functions. These modules include data storage and management, data acquisition, shaft orbit synthesis, shaft orbit simulation, rotor fault simulation, invariant moment calculation and pattern recognition as shown in Fig. 3.

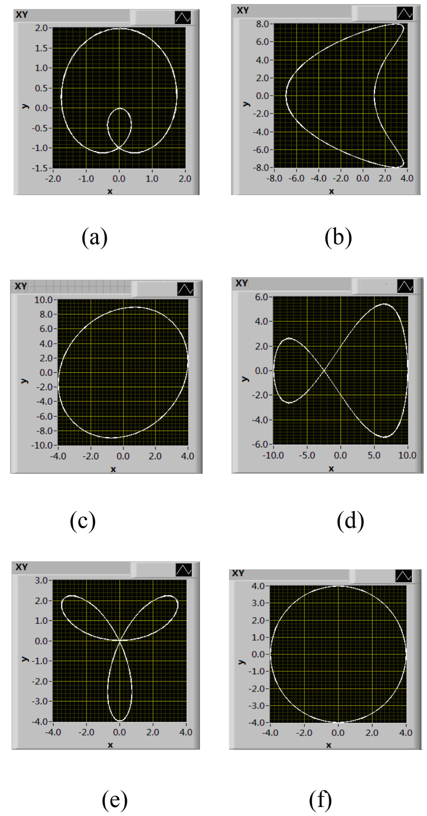

Fig. 4: Typical shaft orbits simulation based on the LabVIEW; (a) oil whirl, (b) rotor misalignment, (c) rotor imbalance, (d) rotor rubbing, (e) oil whip, (f) the ideal state

SHAFT ORBIT AND ROTOR FAULT SIMULATION

Shaft orbit simulation: The shape of shaft orbits contains some fault information, such as rotor imbalance, misalignment, static and dynamic friction, oil whirl and oil film vibration. The fault information database can be established by simulating shaft orbits to facilitate the fault information identification and fault diagnosis.

If two vibration displacement signals $x(t)$ and $y(t)$ are mutually perpendicular, they consist of the baseband frequency and second harmonic component respectively as follows:

$$\begin{cases} x(t)=A_1\sin(\omega t+\alpha_1)+A_2\sin(2\omega t+\alpha_2) \\ y(t)=B_1\cos(\omega t+\beta_1)+B_2\cos(2\omega t+\beta_2) \end{cases} \quad (1)$$

In the formula A_1, A_2, α_1, α_2, B_1, B_2, β_1, β_2, are respectively amplitudes and initial phases of $x(t)$ and $y(t)$. They form a complex signal in the complex plane:

$$z(t) = x(t)+jy(t) \quad (2)$$

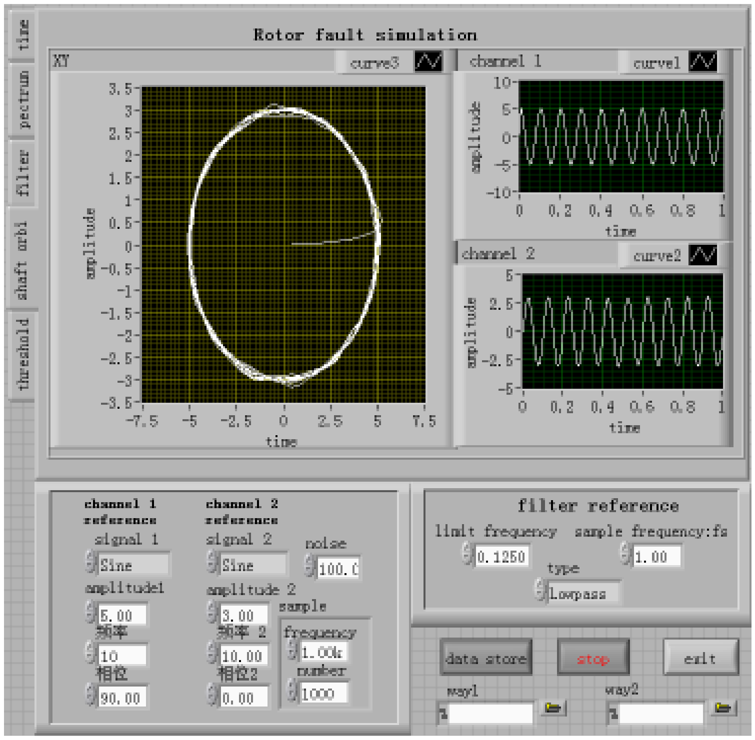

Fig. 5: Control panel of rotor fault simulation

The typical shaft orbits can be simulated by adjusting eight parameters of above formula using LabVIEW as shown in Fig. 4.

Six trajectories from (a) to (f) are respectively corresponding to six kinds of fault phenomena: oil whirl, rotor misalignment, rotor imbalance, rotor rubbing, oil whip, ideal state.

Rotor fault simulation: Research of the rotor fault simulation system is significant to analize and forcast machine fault or repeated demonstration and reconstruct the fault signal. This system can be operated independing on the flexible rotor test bench and data acquisition system. The LabVIEW program need to be introduced an analog signal generator to give the source signals. The system can allow to set analog signal references on the control panel and open or save data by manual operation. Because of many more functions the sub-panels need to be stacked into several layers to be convenient to the operation. The control panel of the rotor fault simulation system is shown in Fig. 5. This system contains some functions such as time-domain analysis, frequency domain analysis, digital filtering, shaft orbit synthesis and threshold alarm.

SHAFT ORBIT RECOGNITION

If a shaft orbit is regarded as a two-dimensional image, the shaft orbit shape is identified by a pattern recognition of image processing. A invariant moment algorithm on the basis of image processing is introduced into shaft orbit identification (Jiang and Li, 2007; Ding and Chang, 1992; Xiao, 2009). The eigenvalues of invariant line moments of discrete data can be calculated by LabVIEW programming. If the curve of the shaft orbit consists of N discrete data, the invariant line moment can be expressed as follows:

$$m'_{pq} = \sum_{i=1}^{N-1} x_i^p y_i^q \Delta s_i \quad (p, q = 0,1,2,3....) \tag{3}$$

The central invariant moment which meets translation invariance is expressed as follows:

$$\mu_{pq} = \sum_{i=1}^{N-1} (x_i - \bar{x})^p (y_i - \bar{y})^q \Delta s_i \quad (p, q = 0,1,2,3....) \tag{4}$$

where $\bar{x}$ and $\bar{y}$ represent graphics centroid coordinates, $\begin{Bmatrix} \bar{x} = m_{10}/m_{00} \\ \bar{x} = m_{10}/m_{00} \end{Bmatrix}$. □ S_i is expressed as follows:

$$\Delta s_i = \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} \tag{5}$$

The line invariant moment η_{pq} based on discrete data can be expressed as follows by normalizing μ_{pq}:

$$\eta_{pq} = \frac{\mu_{pq}}{\mu_{00}^{1+\frac{p+q}{2}}} \quad (p+q \geq 2) \tag{6}$$

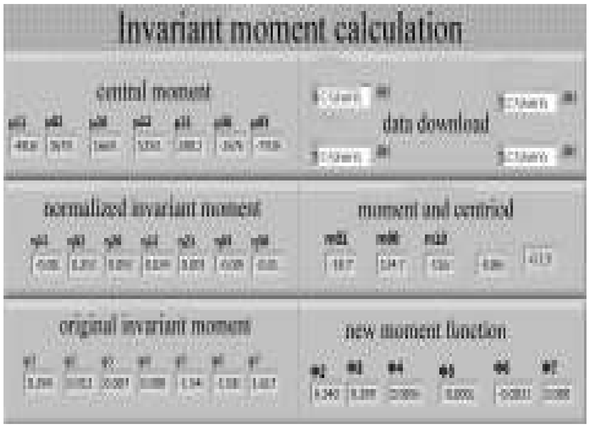

Fig. 6: Control panel of calculation module of invariant moments

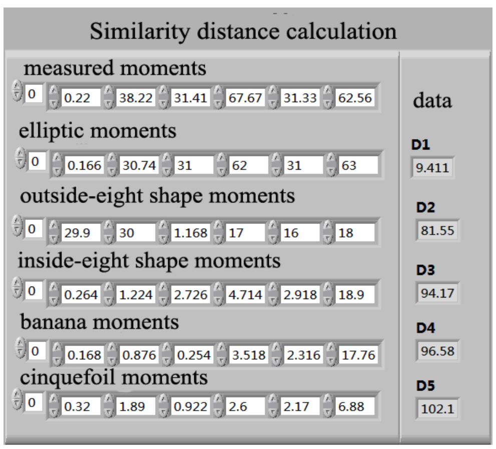

Fig. 7: Control panel of similarity calculation module

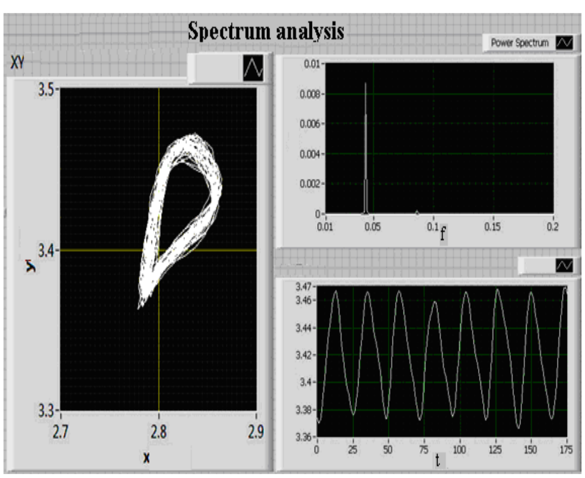

Fig. 8: Control panel of spectrum analysis

According to HU's invariant moment theory seven invariant moment functions are respectively $\varphi_1 \sim \varphi_7$ which have invariable features of rotary, translation and zooming of the graphics. Calculating directly the invariant moments will make a large error when data is discrete. So the original invariant moment algorithm needs to be improved. By introducing the scaling factor ρ, the invariant moments are become $\varphi'_1 \sim \varphi'_7$ and then φ'_1 is regarded as calculation factor to eliminate the effect of scaling factor ρ and the new moment functions $\phi_1 \sim \phi_7$ are constructed (where ϕ_1 is absent).

The invariant moment calculation can be transformed into an array summation in LabVIEW software. The data of the vibration displacement signals $x(t)$ and $y(t)$ is converted into arrays respectively, each element in the array is summed by array summation. The control panel of calculation module of invariant moments is shown in Fig. 6.

The shaft orbits simulated in section two are regarded as reference standards and the eigenvalues of shaft orbits are respectively calculated. The difference between the measured value and the standard value is called the similarity distance which can be regarded as the standard of evaluating the similarity between two shaft orbits. The similarity distance can be calculated as follows:

$$D(x,y) = \|X - Y\| = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2} \quad (7)$$

where X and Y are respectively corresponding to the measured moment and standard moment, n is 6.

Figure 7 is the control panel of calculation module of similarity distance. Where D1~D5 are the similarity distances between the measured moment and standard moments. The calculated results show that the similarity distance D1 of the ellipse is minimum, which indicates the measured shaft orbit is the most similar to the ellipse. So the fault diagnosis conclusion is rotor imbalance.

In order to verify the fault diagnosis result correct or not a spectrum analysis module is developed as shown in Fig. 8. The left ellipse curve on the control panel is the synthetical shaft orbit and the right curves are respectively the single-channel displacement $x(t)$ of the rotor and its spectrum. Two spectrum components appear in spectrum diagram and the two frequency values are multiple and the fundamental frequency is about 45Hz and the second harmonic component is nearly 90Hz. The 99% vibration energy is concentrated in fundamental frequency 45Hz, which is also rotation frequency of the rotor. But the vibration energy of second harmonic component is very small. The spectrum analysis shows that the fault result is rotor imbalance.

The fault diagnosis result based on the invariant moment algorithm is consistent with the conclusion of spectrum analysis, which shows that the shaft orbit measurement and recognition method on LabVIEW is correct and effective.

CONCLUSION

The measurement and identification method of shaft orbits and rotor fault simulation based on LabVIEW software is researched. The shaft orbit of the rotor is real-time measured by data acquisition hardware system built on the flexible rotor test bench; six kinds of shaft orbits containing typical fault characteristics are simulated and a rotor fault simulation system is built. The eigenvalues of the invariant moments of shaft orbits are calculated and then regarded as the reference standard of pattern recognition; the image invariant moments and similarity distances are calculated and analyzed by pattern recognition module. The result shows that the main fault of the rotor is imbalance. The correctness of fault result is verified by spectrum analysis. So the fault diagnosis system of the rotor based on LabVIEW hardware and software is proved effectively.

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