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Research on Vibration State Monitoring and Fault Diagnosis System of Chemical Rotating Machinery

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The signal processing technology is used for the feature extraction of vibration signals of rotating machinery and thus special information can be obtained to diagnose the operation status of rotating machinery. Firstly, the real-time acquisition of vibration signals is studied and a multi-channel real-time vibration signal acquisition system is constructed. Then, the Access database platform is built on this basis and an on-line monitoring and fault diagnosis system of operating status is established to explore the application in specific projects. This paper proposes the application of holographic spectroscopy technology, shafting spatial vibration mode, numerical integration of acceleration signals in the vibration state monitoring and fault diagnosis of chemical rotating machinery. The comparative analysis of rotor signals is conducted through the application of the constructed system and verifies the effectiveness and accuracy of the algorithm. It shows this system can effectively eliminate the slight error of the time domain to a great extent and the monitoring and diagnosis results are more accurate.

1. Introduction

Rotating machinery is widely used in many important fields such as electric power, power, chemical industry, metallurgy and machinery manufacturing, and is usually the key equipment in the production process of enterprises. The rotor system is the core component of the rotating machinery, whose health status not only affects the operation of the mechanical equipment itself, but also may affect normal production. In severe cases, it will cause major losses to the national economy and even lead to the occurrence of safety accidents. In order to ensure normal and safe operation, reduce maintenance costs and improve utilization, it is necessary to conduct the state monitoring and fault diagnosis of mechanical equipment.

In order to meet the needs of chemical engineering, this paper proposes a system and method for vibration condition monitoring and fault diagnosis of rotating machinery based on the Visual Studio software holographic spectrum technology and the shafting spatial vibration mode of the shafting system, which is closer to the actual project to meet the engineering needs. Based on this, the established system is applied to research and analysis of actual engineering cases to explore its application in the engineering field.

2. Literature review

The vibration signal produced during the operation of rotating machinery can reflect the advantages and disadvantages of the running state of the unit and provide important information for fault diagnosis. Amplitude and phase are the main targets of on-site vibration monitoring. It is generally necessary to perform spectrum analysis on discrete data of limited length with a computer. When and and Lvanov analyze the signal spectrum with FFT, the analysis accuracy mainly depends on the aliasing effect, quantization error, spectral leakage, and barrier effect. Through the anti-aliasing filter and matching A/D, the aliasing effect and quantization error can be controlled within the overall accuracy range. For spectral leakage and barrier effects, if the intercepted discrete signal does not meet the full-cycle conditions, a large error will occur, affecting the accuracy of vibration analysis and detrimental to fault diagnosis (And and Lvanov, 2015). Therefore, it is of great significance to study the whole-cycle sampling technique for vibration analysis of rotating machinery. Brusa designed a sampling control circuit that automatically adjusts the sampling rate along with the power

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frequency to achieve full-cycle sampling (Brusa, 2014); Cui et al. combined software and hardware to perform real-time measurement of the entire period of sampling of speed and vibration signals (Cui et al., 2015); Gan et al. performed full-cycle re-sampling of rotor vibration signals with differential and spline interpolation (Gan et al., 2014); Janssens et al. detected key-phase signal cycles to achieve full-cycle sampling with center-of-gravity method (Janssens et al., 2015). The sampling rate at the next moment of speed control at a given time is achieved with hardware. Therefore, only when the rotation speed is stable, the entire cycle can be sampled, and a large error occurs when the rotation speed fluctuates.

Rotary machinery such as centrifugal pumps, power station generators and various axial flow compressors are important devices in petroleum and petrochemical production. In recent years, with the continuous increase in the rotational speed of large-scale rotating machinery, the blades are prone to vibration fracture and cause engineering accidents. On Kwon et al.'s research, according to statistics, blades, cracks, cracks, and other accidents are mostly caused by the vibration of rotating machinery. If the blade vibration frequency can be accurately tested, the blade can be adjusted in advance based on the measurement result, so that the vibration frequency of the blade is shifted by the frequency of the excitation force to ensure the safe operation of the blade (Kwon et al., 2014). There are two methods for vibration measurement of rotating machinery: contact measurement and non-contact measurement, contact measurement can't measure all the blades in the whole class, and it can't be monitored in real time for a long time; due to its simple design, quick installation and wide measurement, it does not affect the flow of steam, the frequency and damping of the blades, and provides on-line monitoring of all blades in the whole class. The non-contact measurement method is the important research direction in future vibration measurement technology for rotating machinery. Yakovlev and Shuvalov's research shows that the vibration measurement system has the advantages of high precision, real-time, and high-speed device monitoring. The system mainly includes these innovations: laser fiber sensors adapted to high-speed real-time monitoring requirements are used. The selected laser fiber sensor has the characteristics of strong anti-electromagnetic interference, a bandwidth of better than 100 MHz, and a measurement distance of 0.5 mm; the method of processing vibration measurement data of rotating machinery is analyzed in detail. The problem that the analysis and processing of high-speed rotating machinery vibration measurement data can't be accurately solved is solved, and the real-time performance of system signal processing is improved; in order to facilitate the experiment, a set of simulation test benches that simulate the operation of a rotating machine is designed (Yakovlev and Shuvalov, 2015; Zaoui et al., 2017). Rolling bearings are the most widely used rotating parts in mechanical equipment and are also one of the vulnerable parts in rotating machinery. In a rotating machine with rolling bearings, approximately 30% of mechanical failures are caused by rolling bearings. Zhao et al.'s study stated that the most common and effective method is to monitor and diagnose the mechanical equipment with vibration signals. Vibration signal analysis has become the most active branch of fault diagnosis (Zhao et al., 2014). The effective clearance of the bearing should be limited to a slightly negative number, which is most ideal, but in the actual process it is very difficult, even with the negative increase of the clearance, the bearing life decreases sharply. Therefore, the bearing is generally selected to have a slightly higher clearance than zero. In fact, the displacement of the center of the shaft is inevitable because of the circular distribution of the steel ball of rolling bearing and the structural characteristics of the clearance. In fact, axial displacement during operation is unavoidable due to the circumferential distribution of the ball bearings of the rolling bearing at equal intervals and structural features of play. In addition, factors such as load and installation gap preload tend to increase the bearing clearance. As the bearing clearance increases, the rotor generates radial runout and causes high vibration. With the radial runout of the rotor, the rotor wears. When the rotor rotates to the corresponding position, a wear occurs, so the increase of the play often causes the increase of the power frequency and its harmonics.

In summary, the measurement methods of bearing clearance of vibration signals and vibration signals of rotating machinery and the related measurement results of rotating machinery are mainly introduced. The application of holographic spectrum technology, spatial vibration mode of shafting, and numerical integration of acceleration signals in the monitoring of vibration status and fault diagnosis of chemical rotating machinery is proposed. Through the application of this system, the rotor signal is compared and analyzed, and the effectiveness and accuracy of the algorithm are verified. The results show that the system effectively eliminates small errors in the time domain to a great extent, and the monitoring and diagnosis results are more accurate.

3. Construction of vibration monitoring and fault diagnosis system for rotating machinery

Rotating machinery is the material and technical basis for modern industrial production and processing. The rotating machinery and equipment in sub-health or faulty will lead to high-energy operation and may cause the abnormal production and operation in the industry, which will interrupt the customer service. In more severe cases, it will cause great harm to the environment and people. Maintenance is an essential part in the working process of rotating machinery. Maintenance can not only discover the sub-health or fault status, ensure the effectiveness and reliability, prevent the occurrence of vicious accidents and avoid the casualty of personnel; it can also improve the output and quality of the products served by the rotating machinery, avoid unnecessary energy consumption and environmental pollution caused by the sub-healthy operation or unexpected failure of rotating machinery in the production process, avoid huge economic losses and save energy. The maintenance of rotating machinery includes post-event, improvement, and preventive maintenance. The specific maintenance methods are shown in Figure 1.

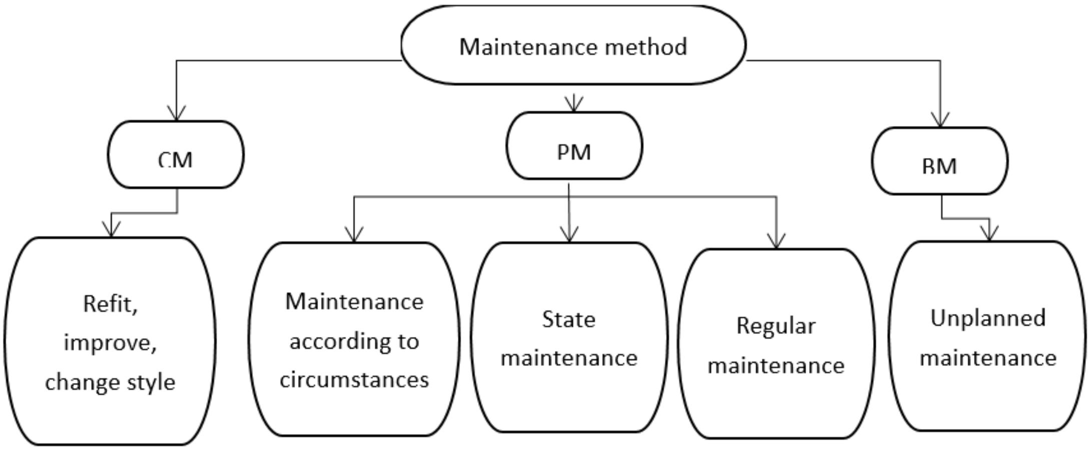

Figure 1: Common methods of maintenance of rotating machinery and equipment

3.1 Development ideas of the system

This paper develops the equipment state monitoring and diagnosis system based on the VB.NET under Microsoft Visual Studio environment. Considering that the most prominent advantage of the C/S (client-server) mode application system is that it does not depend on the advantages of the external network environment, a remote state monitoring and diagnosis system structure based on C/S mode is constructed. The system is designed to meet the needs of engineering and provide a vibration state monitoring and fault diagnosis system based on Visual Studio software platform, which is closer to the actual project to meet the needs of engineering.

3.2 The overall framework of the system

The equipment condition monitoring and diagnosis system includes a number of subsystems, namely, "multi-channel real-time signal acquisition system," "database system based on Access" and "signal analysis system." The multi-channel real-time signal acquisition system performs on-line real-time state monitoring including time domain waveforms, preliminary analysis of amplitude spectrum, peak alarm monitoring and effective value alarm. Then, through the data storage module, it goes through the data classification storage for further analysis and processing. The database system based on Access is mainly used for the retrieval and management of data and the management of users and monitoring plans. The signal analysis system is an off-line analysis that extracts data from the database. Then, it further analyzes the vibration signal, extracts signal features, performs fault diagnosis and prediction and generates reports.

The vibration state monitoring and fault diagnosis system of rotating machinery mainly includes 3 main function modules: multi-channel real-time signal acquisition system, database system based on Access and signal analysis system.

3.3 Application of state monitoring and fault diagnosis system

The research paper for the application of the state monitoring and fault diagnosis system mainly simulates a 600,000 kilowatt turbine shaft vibration table driven by a direct current motor and a three-stage gearbox; six turbine rotors with and the diameter of each rotor is 31mm-100mm. the bearing is a circular sliding bearing; the speed range of rotors is 0-9000r/min. The data acquisition system is a multi-channel real-time signal acquisition system developed based on the Yiheng data acquisition instrument EPMAX. The sensor is a WT type eddy current sensor manufactured by Houde Instrument Co., Ltd. The sensitivity of the sensor is 8v/mm and the two layers are 0-500um. In a certain section, the installation position of the sensor is 90 degree. The installation position of the radial vibration probe of the shaft and the maximum distance from the bearing are shown in Table 1:

Table1: Shaft radial vibration Probe mounting position and bearing maximum distance

Measure bearing diameter	Installation and bearing the maximum distance between
0-76mm	25mm
76-508mm	76mm
>508mm	152mm

The simulation of a 600,000-kilowatt turbine shaft vibration table is shown in Figure 2:

Figure 2: 600 MW turbine shaft shaker simulation

The data of 4 cross-sections of the 600,000-kilowatt turbine shaft vibration table at the speed of 375 r/min are measured. The information of the vibration frequency data of 4 cross-sections at the horizontal direction of the shaft at a certain time is: the amplitude of section 1 is 2.4 Um and the phase is -69 degrees; the amplitude of section 2 is 6.4um and the phase is -64 degrees; the amplitude of section 3 is 7.1um and the phase is -53 degrees; the amplitude of section 4 is 5.6um and the phase is -66 degrees, as is shown in Table 2:

Table 2: Turbine Shafting Shaking Table Measurement Cross Section Data

Measurement section	Amplitude	Phase
1	2.4um	-69°
2	6.4um	-64°
3	7.1um	-53°
4	5.6um	-66°

The vibrational base frequency component of the cross-section at the horizontal direction measured on the basis of Table 2 is shown in Table 3.

Table 3: Cross section horizontal direction vibration fundamental frequency component

Rotating speed	Measurement section 1	Measurement section 2	Measurement section 3	Measurement section 4
375r/min	2.4∠291	6.4∠296	7.1∠307	5.6∠294

The above table shows the base frequency component of the cross-section at the rotate speed of 375. With the increase of the rotate speed, these values will also change greatly. The different cross-section data under the stable operation state at the rotate speed of 544r/min is shown in Table 4:

Table 4: Speed at 544r / min steady state of different cross-section data

Rotating speed	Measurement section 1	Measurement section 2	Measurement section 3	Measurement section 4
544r/min	2.1∠286	65.8∠297	6.2∠312	5.4∠288

When the rotate speed is 544r/min, the information of the vibration frequency data of 4 cross-sections at the vertical direction at the rotate speed of 544r/min is shown in Table 5:

Table 5: 544r / min vertical section of four cross-section vibration data frequency information

Measurement section	Amplitude	Phase
1	2.3um	25°
2	7.1um	15°
3	7.6um	-29°
4	20.2um	54°

The vibration amplitude at the horizontal direction of section 1 is the smallest and the vibration amplitude of the working frequency of section 2 is greater than that of section 1, which is due to the increase in the rotor weight of the turbine where the section 2 is located. The cross-section 3 and the cross-section 2 have similar vibration and the vibration in the vertical direction is slightly higher than that in the horizontal direction; however, the vibration in the horizontal direction of the cross-section 4 at the farthest end of the motor also increases significantly; it indicates that there is a looseness problem in the bearing of cross-section 4 in the vertical direction. The vibrational phase of the four cross-sections at a certain moment are inconsistent but not much different. The vibrational frequency component of four cross-sections doubles at the stable rotate speed of 544 r/min.

4. Conclusion

The experiment shows that the time domain waveform, as the original data of the vibration signal, is intuitive and very easy to be understood, providing the most authentic information. The prior analysis of the time domain waveform often plays an important role in fault diagnosis. Based on the time domain waveform, the axial trajectory integrates the vibration signals in both directions and carries a wealth of diagnostic information, which is an important auxiliary method for fault diagnosis of rotating machinery.

Frequency domain analysis is the most important and commonly used analysis method for signal processing in fault diagnosis of rotating machinery; it is very difficult to extract many fault features through the time domain analysis, which can be significantly expressed in the frequency domain. However, the spectral analysis method like amplitude spectrum separates the amplitude and phase in the vibration signal. The vibration in rotor in the bearing of the cross-section in the vertical and horizontal direction is separated from each; the holographic spectroscopy technique effectively overcomes these two major defects. Based on the time-domain waveform and spectrogram of vibration signals, the two-dimensional holography technology combined with the filter axis trajectory technology can effectively extract the distinguishing features of common faults such as shaft cracks and the collision and abrasion of moving and stationary parts. The holographic waterfall map integrates the amplitude and phase of the vibration in the vertical and horizontal direction, which can reveal the vibration characteristics of the rotating machinery more effectively when turning on and turning off the machine compared with the traditional waterfall map. The vibration characteristics of the shaft system in large-scale rotating machinery is an important index. The vibration mode of the shaft system can clearly represent the comparison of vibration among vibration trajectories of components of the same order on multiple sections and their phase relationship. VS.NET, as a development platform, supports a variety of programming languages. The holographic spectrum analysis software based on software platform is not only flexible and convenient for operation, but also closer to the actual application.

This paper has studied the simulation data and a large amount of experimental data for the application of holographic spectroscopy and the shafting space vibration mode and obtained a lot of valuable fault information; however, for the restraint of practical conditions, the study of vibration signals of machinery in the actual engineering site is not thorough enough and it lacks a large number of engineering applications. The established holographic spectrum analysis system based on VS.NET can be well applied to the vibration state monitoring and fault diagnosis of machinery and extensive application researches should be done to establish the fault database.

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