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Recent Progress on Mechanical Condition Monitoring and Fault diagnosis

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Abstract 机械故障研究三个方面：故障机理、信号处理与特征提取、故障分析推定趋势是向基于智能信息处理的机械故障诊断系统发展，可自学习自迭代。

Mechanical equipments are widely used in various industrial applications. Generally working in severe conditions, mechanical equipments are subjected to progressive deterioration of their state. The mechanical failures account for more than 60% of breakdowns of the system. Therefore, the identification of impending mechanical fault is crucial to prevent the system from malfunction. This paper discusses the most recent progress in the mechanical condition monitoring and fault diagnosis. Excellent work is introduced from the aspects of the fault mechanism research, signal processing and feature extraction, fault reasoning research and equipment development. An overview of some of the existing methods for signal processing and feature extraction is presented. The advantages and disadvantages of these techniques are discussed. The review result suggests that the intelligent information fusion based mechanical fault diagnosis expert system with self-learning and self-updating abilities is the future research trend for the condition monitoring fault diagnosis of mechanical equipments.

Keywords: Condition monitoring; Fault diagnosis; Vibration; Signal processing

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机械设备故障诊断技术包含：状态监测
和故障诊断

技术原理：监测核心部件运行与静止状态信息 - 分
析提取信息特征 - 对比历史数据量化评估状态，预
测可能故障及状态趋势 - 确定维护方案

1. Introduction

With the development of modern science and technology, machinery and equipment functions are becoming more and more perfect, and the machinery structure becomes more large-scale, integrated, intelligent and complicated. As a result, the component number increases significantly and the precision requirement for the part mating is stricter. The possibility and category of the related component failures therefore increase greatly. Malignant accidents caused by component faults occur frequently all over the world, and even a small mechanical fault may lead to serious consequences. Hence, efficient incipient fault detection and diagnosis are critical to machinery normal running. Although optimization techniques have been carried out in the machine design procedure and the manufacturing procedure to improve the quality of mechanical products, mechanical failures are still difficult to avoid due to the complexity of modern equipments. The condition monitoring and fault diagnosis based on advanced science and technology acts as an efficient mean to forecast potential faults and reduce the cost of machine malfunctions. This is the so-called mechanical equipment fault diagnosis technology emerged in the nearly three decades [1, 2].

Mechanical equipment fault diagnosis technology uses the measurements of the monitored machinery in operation and stationary to analyze and extract important characteristics to calibrate the states of the key components. By combining the history data, it can recognize the current conditions of the key components quantitatively, predicts the impending abnormalities and faults, and prognoses their future condition trends. By doing so, the optimized maintenance strategies can be settled, and thus the industrials can benefit from the condition maintenance significantly [3, 4].

The contents of mechanical fault diagnosis contain four aspects, including fault mechanism research, signal processing and feature extraction, fault reasoning research and equipment development for condition monitoring and fault diagnosis. In the past decades, there has been considerable work done in this general area by many researchers. A concise review of the research in this area has been presented by [5, 6]. Some landmarks are discussed in this paper. The novel signal processing techniques are presented. The advantages and disadvantages of these new signal processing and feature extraction methods are discussed in this work. Then the fault reasoning research and the diagnostic equipments are briefly reviewed. Finally, the future research topics are described in the point of future generation intelligent fault diagnosis and prognosis system.

2. Fault Mechanism Research

Fault Mechanism research is a very difficult and important basic project of fault diagnosis, same as the pathology research of medical. American scholar John Sohre, published a paper on "Causes and treatment of high-speed turbo machinery operating problems (failure)", in the United States Institute of Mechanical Engineering at the Petroleum Mechanical Engineering in 1968, and gave a clear and concise description of the typical symptoms and possible causes of mechanical failure. He suggested that typical failures could be classified into 9 types and 37 kinds [7]. Following, Shiraki [8] conduced considerable work on the fault mechanism research in Japan during 60s-70s last century, and concluded abundant on-site troubleshooting experience to support the fault mechanism theory. BENTLY NEVADA Corporation has also carried out a series experiments to study the fault mechanism of the rotor-bearing system [9]. A large amount of related work has been done in China as well. Gao et al. [10] researched the vibration fault mechanism of the high-speed turbo machinery, investigated the relationship between the vibration frequency and vibration generation, and drew up the table of the vibration fault reasons, mechanism and recognition features for subsynchronous, synchronous and super-synchronous vibrations. Based on the table they proposed, they have classified the typical failures into 10 types and 58 kinds, and provided preventive treatments during the machine design and manufacture, Installation and maintenance, operation, and machine degradation. Xu et al. [11] concluded the common faults of the rotational machines. Chen et al. [12] used the nonlinear dynamics theory to analyze the key vibration problems of the generator shaft. They established a rotor nonlinear dynamic model for the generator to comprehensively investigate the rotor dynamic behavior under various influences, and proposed an effective solution to prevent rotor failures. Yang et al. [13] adopted vibration analysis to study the fault mechanism of a series of diesel engines. Other researchers have done a lot in the fault mechanism of mechanics since 1980s, and have published many valuable papers to provide theory and technology supports in the application of fault diagnosis systems [14-18]. However, most of the fault mechanism research is on the qualitative and numerical simulation stage, the engineering practice is difficult to implement. In addition, the fault information often presents strong nonlinear, non stationary and non Gaussian characteristics, the simulation tests can not reflect these characteristics very accurately. The fault diagnosis results and the application possibility may be influenced significantly. As a result, the development of the fault diagnosis technique still faces great difficulties.

3. Advanced Signal Processing and Feature Extraction Methods

Advanced signal processing technology is used to extract the features which are sensitive to specific fault by using various signal analysis techniques to process the measured signals. Condition information of the plants is contained in a wide range of signals, such as vibration, noise, temperature, pressure, strain, current, voltage, etc. The feature information of a certain fault can be acquired through signal analysis method, and then fault diagnosis can be done correspondingly. To meet the specific needs of fault diagnosis, fault feature extraction and analysis technology is undergoing the process from time domain analysis to Fourier analysis-based frequency-domain analysis, from linear stationary signal analysis to nonlinear and nonstationary analysis, from frequency-domain analysis to time-frequency analysis.

Early research on vibration signal analysis is mainly focused on classical signal analysis which made a lot of research and application progress. Rotating mechanical vibration is usually of strong harmonic, its fault is also usually registered as changes in some harmonic components. Classical spectrum analysis based on Fourier transform (such as average time-domain techniques, spectrum analysis, cepstrum analysis and demodulation techniques) can extract the fault characteristic information effectively, thus it is widely used in motive power machine, especially in rotating machinery vibration monitoring and fault diagnosis. In a manner of speaking, classical signal analysis is still the main method for mechanical vibration signal analysis and fault feature extraction. However, classical spectrum analysis also has obvious disadvantages. Fourier transform reflects the overall statistical properties of a signal, and is suitable for stationary signal analysis. In reality, the signals measured from mechanical equipment are ever-changing, non-stationary, non-Gaussian distribution and nonlinear random. Especially when the equipment breaks down, this situation appears to be more prominent. For non-stationary signal, some time-frequency details can not be reflected in the spectrum and its frequency resolution is limited using Fourier transform. New methods need to be proposed for those nonlinearity and non-stationary signals. The strong demand from the engineering practice also contributes to the rapid development of signal analysis. New analytical methods for non-stationary signal and nonlinear signal are emerging constantly, which are soon applied in the field of machinery fault diagnosis. New methods of signal analysis are main including time-frequency analysis, wavelet analysis, Hilbert-Huang transform, independent component analysis, advanced statistical analysis, nonlinear signal analysis and so on. The advantages and disadvantages of these approaches are discussed below.

4. Research on Fault Reasoning

At present, many methods are adopted in the process of diagnostic reasoning. According to the subject systems which they belong to, the fault diagnosis can be divided into three categories: (1) the fault diagnosis based on control model; (2) the fault diagnosis based on pattern recognition; (3) the fault diagnosis based on artificial intelligence. Among them, the fault diagnosis based on control model needs to establish model through theoretic or experimental methods. The changes of system parameters or system status could directly reflect the changes of equipments physical process, and hence it is able to provide basis for fault diagnosis. This technology refers to model establishment, parameters estimation, status estimation, application of observers, etc. Since it requires accurately system model, this method is not economically feasible for the complicated devices in the practice.

Pattern recognition conducts cluster description for a series of process or events. It is mainly divided into statistical method and language structure method. The fault diagnosis of equipments could be recognized as the pattern recognition process, that is to say, it recognizes the fault based on the extraction of fault characteristics. There are many common recognition methods, including bayes category, distance function category, fuzzy diagnosis, fault tree analysis, grey theory diagnosis and so on. Recent years, some new technologies have been also applied in the field of the fault diagnosis of rotary machines, such as the combination of fuzzy set and neural network, the dynamic pattern recognition based on hidden markov model, etc.

5. Research and Development of Fault Diagnosis Devices

Fault diagnosis technology ultimately comes down to the actual devices, and at present research and development of fault diagnosis devices is in the following two directions: (1) Portable vibration monitoring and diagnosis (including data collector system), and (2) On-line condition monitoring and fault diagnosis system. Portable instrument is mainly adopted single-chip microcomputers to complete data acquisition, which has certain ability for signal analysis and fault diagnosis. On-line monitoring and diagnosis system is usually equipped with sensors, data acquisition, alarm and interlock protection, condition monitoring subsystem, etc. And it is also fitted with rich signal analysis and diagnosis software. These software include America BENTLY Corporation 3300, 3500 and DM2000 systems, America Westinghouse Company PDS system, the 5911 system developed by ENTECK and IRD Company, Japan Mitsubishi MHM system, the Danish B&K Company B&K 3450 COMPASS system, etc. China has also successively developed large on-line monitoring and fault diagnosis system, which has been put into use on steam turbine and other important equipments.

Based on the realization of condition monitoring of equipments, network diagnostics center can monitor and diagnose the operation of equipments at any time through the network to achieve the long distance information transmission. The remote monitoring system can also achieve the collaborative diagnosis of production equipments, multiple diagnostic systems serve the same piece of equipment, and multiple devices share the same diagnostic system.

6. Conclusions

To achieve a dynamic system condition monitoring and fault diagnosis, primary task is the need to get enough reliable characteristic information from the system. Due to the fluctuation of the system itself and the environment disturbance, reliable signal collection is seriously affected. It is therefore very urgent for advanced signal processing technology to eliminate noise to get true signal. No matter classical or advance fault diagnosis techniques, they have achieved great progress in various applications. In the point of systematic view, every technology is a part of the whole diagnostic system, and the efficient fusion of these parts will provide best performance for the condition monitoring and fault diagnosis. Thus, the fault mechanism research, signal processing and feature extraction, fault reasoning research and equipment development will connect even tighter to form an effective fault diagnostic expert system in the future. To realize the expert system, the core issue is to break through the bottleneck of knowledge acquisition, update the data model in a reliable manner and provide good generalization ability of the expert system. By doing so, the fault diagnostic expert system can offer accurate estimation of the potential abnormalities, and prevent them before breaking out to ensure the normal operation of the machines. Hence, the loss caused by the machine breakdowns can be minimized significantly.

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