Research Status and Development of Fault Diagnosis for Active Magnetic Bearings

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Abstract: Active magnetic bearings (AMB), a typical mechatronic product, have been successfully applied in industrial turbo machinery. Their main advantages are high speed, non-contact, no friction without lubrication, low noise, low power consumption, which give magnetic bearings broad application prospects. If magnetic bearings are to be applied to industry, the problems of condition monitoring and fault diagnosis must be solved. This paper analyzes the basic principles of fault diagnosis and fault diagnosis technology for rotating machinery, introduces the status quo of fault diagnosis for magnetic bearings, and proposes research directions and applications in the future.

Keywords: Active Magnetic Bearings, Fault Diagnosis, Rotating Machinery, Status Quo of Research

Introduction

With the rapid development of modern industry, more and more demanding performances requirements of rotating machinery are proposed, required rotation speed and accuracy of the rotor, the core component of rotating machinery, is increasing. For other rotating machinery which work in extreme hot or cold environment such as military and aerospace, in addition to requirements to withstand the harsh environment, there are strict requirements on the controllability, security and reliability of the rotor. To summarize, mainly high-speed, high accuracy, controllability, reliability, high efficiency and adaptability to complex adverse circumstances, to meet these requirements at the same time, magnetic bearing technology should be mentioned first. Only on the basis of correct monitoring on working condition of magnetic rotor can we take effective control methods to ensure the controllability of it, so that the rotor can run stable. But in the actual operation process of the rotor, there might be instability, vibration and other faults. If these problems are not timely responded and controlled, the rotor will be unstable and can not run properly. Monitoring and fault diagnosis for magnetic rotor can guarantee the reliability and safety of the rotor when rotating with high speed, reduce maintenance costs of magnetic bearings and increase the plant productivity.

Basic Principles of Fault Diagnosis

As the composition and working methods of various types of equipment always differ a lot, the diagnostic methods used in different fields can not be exactly the same. The diagnostic methods which are succeed in one field or for one device may not apply or do not fully apply to another area or device. Therefore, the description of the problem in diagnosis, the use and organization of diagnostic knowledge, the type and access to diagnostic information, or even the nature of the task can be different for various areas and devices. In this case, diagnostic theory, method and strategy unified within a certain extent must be established for different diagnostic areas and devices. The equipment fault diagnosis technology must be formed as a unified discipline. So we must make research on the basic concept of fault diagnostic system and common characteristics of various diagnostic problems, establish common methods adapted to all diagnostic areas.

As the complexity of equipment faults and the complex relationship between faults and symptoms, fault diagnosis for equipment is considered as a process of exploration. For the subject of fault diagnosis, the key is not to study the fault itself, but to study the methods of fault diagnosis. Because of its complexity, several methods must be used instead of a single method. It can be said that either method works on the fault diagnosis should be used. The principle and method of fault diagnosis must be explored from various disciplines, which makes fault diagnosis technology presents the characteristics of multi-disciplinary cross [1].

Traditional fault diagnostic methods

First, use various physical and chemical principles and methods, through a variety of physical and chemical phenomena which occur with the fault, to detect faults directly. For example, vibration, sound, light, heat, electricity, magnetism, radiation, chemical and other means are used to observe its rules of change and characteristics for the detection and diagnosis of faults. This method is image, fast, and effective, but can not detect all the faults.

Secondly, using the sign corresponding to the fault is the most commonly used and mature way to diagnose faults. Take rotating machinery as an example, vibration and signs of frequency spectrum characteristic reflect the features of fault best, and are the most beneficial means for fault diagnosis. Therefore, in-depth study on mechanisms of various faults and signs corresponding to various faults should be carried out. In the diagnosis process, first analyze all the signals obtained during the operation of the equipment, extract various information of signals, obtain signs related to the faults, and then use these signs to diagnose faults. There is no simple one to one correspondence between the sign and the fault, so using signs for fault diagnosis is always an iterative process of exploring and solving.

Intelligent fault diagnostic methods

Based on the traditional diagnostic methods above, using theory and methods of artificial intelligence for fault diagnosis and developing intelligent fault diagnostic methods are new ways of fault diagnosis, they are now widely used as the main direction of fault diagnosis.

The purpose of artificial intelligence is to make computer do intelligent tasks which can only been done by human originally, including reasoning, understanding, planning, decision-making, abstraction, learning and other functions. Expert system is an important form to achieve artificial intelligence; it has been widely used for diagnosis, interpretation, design, planning, decision-making and other fields. At present, a series of expert systems have been developed, and have achieved very good results.

The basic structure of expert system includes four components

（1）Knowledge Base

（2）Inference Engine

（3）Working Memory

（4）Man-Machine Interface

The core issue of expert system is knowledge acquisition and knowledge representation. Knowledge acquisition is the "bottleneck" of expert system; reasonable knowledge representation method can rationally organize knowledge and improve the capacity of expert system. A lot of work must be done to make diagnostic expert system have a wealth of knowledge. Mechanism analysis on various faults of the equipment must be made; some of them need analysis of mathematical model and theoretical analysis. Field tests and model tests should be conducted. Especially summarize the diagnostic experience of experts in the field to organize formal knowledge description which is acceptable for computers. the theory and methods of computers to obtain knowledge automatically also need to be studied. All these are necessary for the effective work of expert system. Figure1 shows the components of an expert system for fault diagnosis of equipment.

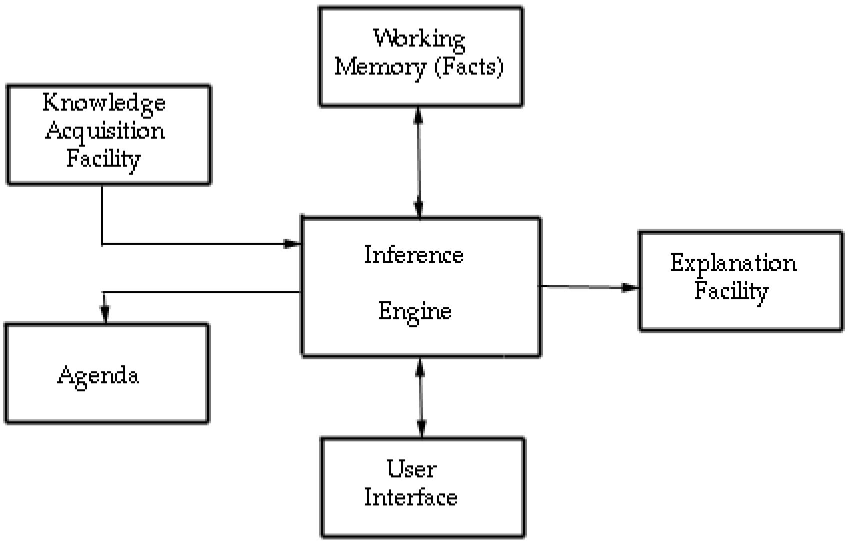

Fig.1 Components of an expert system

Mathematical Methods for Fault Diagnosis

Fault diagnosis technology as a discipline is still in formation and development, the latest scientific achievements in various disciplines should be used extensively, especially through variety of effective mathematical tools. Mathematical methods can be used for fault diagnosis include: diagnostic methods based on pattern recognition method, diagnostic methods based on probability and statistics, diagnostic methods based on fuzzy mathematics, diagnostic methods based on reliability analysis and fault tree analysis, And type geometry, wavelet transform, neural networks and other new developed branches of mathematics used in fault diagnosis, etc.

Fault Diagnosis for Rotating Machinery

Fault diagnosis technology has been greatly improved since 1970s and 1980s, with the development of modern large-scale production and technological progress, the complexity of equipment keeps increasing, how to ensure the safe operation of equipment has become a very pressing issue. Equipment fault diagnosis technology is one of the basic moves to ensure the safe operation of equipment, it can make early prediction of the equipment failure, judge the reasons for the failure, put forward countermeasures and suggestions to avoid or reduce accidents. Equipment fault diagnosis technology has extensively absorbed the latest achievements of modern science and technology. It is closely related to the performance and operation rules of the diagnostic object; it also makes extensive use of modern mathematics, mechanics, physics, electronics, information technology, computer technology and other subjects. Equipment fault diagnosis technology is a multi-disciplinary cross-cutting and integration of new disciplines. In particular, the application of artificial intelligence and the development of intelligent fault diagnosis technology have given fault diagnosis technology a new look; there have been a large number of works on fault diagnosis, including its basic principles, technologies and applications[2].

Fault diagnosis in accordance with the diagnosis object can be divided into: fault diagnosis of rotating machinery, fault diagnosis of reciprocating machinery, fault diagnosis of machine parts, fault diagnosis of engineering structure, fault diagnosis of hydraulic equipment and fault diagnosis of electrical equipment.

Rotating machinery condition detection and fault diagnosis system is one of the most representative applications of the equipment fault diagnosis technology in national economy. The research and development of rotating machinery diagnosis system can be divided into five levels in general: sensors, portable instrumentation and analytical instruments, on-line monitoring instrumentation systems, computerized monitoring and analysis system, intelligent diagnostic systems. With people's increasing attention to fault diagnosis, equipment condition monitoring and fault diagnosis technology has been developing; diagnostic analysis methods are continuously improving. Current diagnostic methods can be broadly classified into the following types: First, using traditional FFT method to carry out manual analysis and diagnosis of equipment failure according to frequency-domain characteristics of the signal; Second, using reasoning model of expert system for intelligent diagnosis; Third, establish the neural network diagnosis model by mimicking the function of brain neurons, based on the study of modern neurophysiology; Forth, using fuzzy clustering method to carry out fuzzy diagnosis for equipment. From the point of diagnosis, each method has its own characteristics. When the equipment failure works in the steady-state case, using traditional FFT method to diagnose is more effective and widely used. Due to the limit of database, completeness of knowledge for failure cases, as well as randomness and diversity of actual faults, the current application of expert system and neural networks for intelligent diagnosis is affected to a certain extent, but they are the focus of current research and have broad application prospects. Owing to the need of equipment failure diagnostics, a great deal of manpower and material resources have been invested to develop a number of rotating machinery condition monitoring and fault diagnosis systems, which are constantly developing.

Research on online fault diagnosis technology and its application of rotating machinery in particular large rotating machinery, has made some achievements, and developed a corresponding engineering practical online monitoring and fault diagnosis system. United States is one of the countries which carry out research on the earliest fault diagnosis technology, and WHEC is the most effective, it engaged in machinery development of rotating machinery fault diagnosis of since 1976, and has grown into a network-oriented

Turbo Intelligent Fault Diagnosis Expert System - Power AID system in 1990. Meanwhile the U.S. ENTER-IRD has its own characteristics in offline and online vibration monitoring, diagnostic systems and testing equipment, and has been supporting many companies for their large unit testing protection systems.

Research Status of Fault Diagnosis for Active Magnetic Bearings

Current research on fault diagnosis is mainly aimed at the traditional bearing rotor; the magnetic bearings are quite different from traditional bearings, with stiffness and damping adjustable.In-depth study on magnetic rotor condition monitoring and fault diagnosis has been carried out, certain results are achieved on condition monitoring, fault identification and fault diagnosis of magnetic rotor. M N Sahinkaya*[3][4], Department of Mechanical Engineering, Faculty of Engineering and Design, University of Bath, UK, presents a method of online fault identification in rotor/magnetic bearing systems using wavelet analysis, The approach is extended further to identify changes in external factors, such as unbalance and rotor dynamics. Various faults and perturbations are examined experimentally, and the ability of the controller to detect and compensate for these changes is demonstrated. Darmstadt University of Technology in Germany [5][6] use active magnetic bearings as an identification and diagnosis tool for turbo machines. The identification and diagnosis procedures are based on frequency response functions. International Center for Magnetic Bearings, Switzerland, deals with the detection and correction of sensor and actuator faults in active magnetic bearing systems with decentralized control. Algorithms for the detection and correction of the faults are presented, and their effectiveness is shown on an experimental test rig. Seung-Jong Kim and Chong-Won Lee[7] propose an on-line diagnosis scheme for sensor faults in an active magnetic bearing system equipped with built-in force transducers. The scheme, utilizing redundant signals, i.e., displacement, current, and force, is based on the causality between faults and symptoms. The view of the monitoring system can be seen from Figure 2[8].

Fig.2 AMB monitoring system

Wuhan University of Technology has done some related work, Feng Bin[9] sets up a magnetic rotor condition monitoring system, establishes magnetic rotor database, classifies collected data and identifies data storage thinning program, makes analysis and explanation on displacement sensor fault and the fault caused by collisions which occur when magnetic rotor floats. Ku Shao-ping[10] establishes a magnetic bearing multi-sensor data model, and makes a simulation study on the control system performance and the causes of two kinds of typical faults: circuit delay and noise disturbance. Through the research on magnetic bearing control system fault diagnosis based on real-time task scheduling algorithm, a task scheduling algorithm considering reliability and fault diagnosis is proposed. Cui Donghui[11] from Nanjing University of Aeronautics and Astronautics focuses on active magnetic bearing system using differential displacement sensor, theoretically analyzes the relationship between controller output signal, rotor disturbance forces and sensor fault signal, and on this basis, sensor fault identification method is proposed based on adaptive filtering, he also does some simulation study on this method with Matlab, and experiment is made in an active magnetic bearing test rig. Nan-Chyuan Tsai[12], National Cheng Kung University, Taiwan, China, combines two diagnosis methodologies by using both state estimators and parameter estimators to detect, identify and analyze actuators and sensors faults in AMB/rotor systems. And a full fault diagnosis for active magnetic bearing and rotor systems to monitor the closed-loop operation and analyze fault patterns on-line in case any malfunction occurs is proposed.

Prospects

In view of the research status on condition monitoring and fault diagnosis of magnetic bearings, most studies are still focused on the identification and diagnosis of partial failure,it is very urgent to develop a practical magnetic bearing rotor condition monitoring and fault diagnosis system. Researchers on magnetic bearings should intensify research efforts in this area, make full use of existing fault diagnosis methods, such as frequency-domain diagnostics, time-domain analysis, statistical analysis, non-stationary signal analysis, information theory analysis and artificial intelligence methods, and further promote the industrial application of magnetic bearing technology.

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