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Research on active magnetic bearing applied in Chinese modular high-temperature gas-cooled reactor

Guojun Yang*, Zhengang Shi, Ni Mo, Lei Zhao

Institute of Nuclear and New Energy Technology of Tsinghua University, The Key Laboratory of Advanced Reactor Engineering and Safety, Ministry of Education, Beijing 100084, China

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ABSTRACT

The modular high-temperature gas-cooled reactor (MHTGR) is one candidate for the fourth generation nuclear energy system technology. It has distinct advantages in terms of inherent safety, economics potential, high efficiency, potential usage for hydrogen production, etc. It is very attractive and competitive in the world, and has a broad development prospects. With the success of 10 MW high-temperature gas-cooled reactor (HTR-10), constructed by Institute of Nuclear and New Energy Technology (INET) of Tsinghua University of China, a larger commercial MHTGR nuclear power plant, namely the HTR-PM, is proposed. At the same time, another plan for higher efficiency, namely the HTR-10GT (direct gas-turbine), is also proposed to study. However, the bearing technology used in the primary loop is becoming an important problem because of the special environment of the reactor. Active magnetic bearing (AMB) is replacing mechanical bearing as the perfect sustaining assembly for the primary loop because they have several advantages: they are free of contact, do not require lubrication, are not subject to the contamination of wear, have endurance, and control performance very well. But there is no successful precedent for nuclear power station in the world. AMB's practicality, reliability, stability and so on are all needed to study by theory and experiment. INET are engaged in these research works and experiments. These works will be introduced and summarized in this paper. It offers the important base for AMB applied in the modular high-temperature gas-cooled reactor.

1. Introduction

Starting from the gas-cooled reactors in the 1950s and the advanced gas-cooled reactor in the 1960s and the high temperature reactor "Dragon" in 1964, the high-temperature gas-cooled reactors (HTGR) have been developed for nearly 50 years. The concept of the modular high-temperature gas-cooled reactor (MHTGR, such as HTR-MODUL designed in Germany and MHTGR designed in US), which is only employing by inherent characteristics to ensure safety, was proposed more than 20 years. MHTGR is not only excellent in its safety performance, but it is also very market flexible. It becomes one candidate for the fourth generation nuclear energy system technology. Therefore, the MHTGR is very attractive and competitive in the world, many research and engineering projects are planned and are ongoing, for example, the South African PBMR project, the US–Russia GT-MHR project, the US NGNP (Next Generation Nuclear Power) in Idaho, the HTTR in Japan, the French HTGR program, and the Chinese high-temperature gas-cooled reactor-pebble bed module (HTR-PM) demonstration project (Zuoyi Zhang et al., 2006).

China began research work on pebble-bed high temperature gas-cooled reactors in the mid-1970s. The 10 MW high-temperature gas-cooled test reactor (HTR-10) is the first module high-temperature gas-cooled test reactor in the world and the HTR-10 project has been successfully designed and built at the Institute of Nuclear and New Energy Technology (INET) of Tsinghua University of China (Xu and Zuo, 2002).

On the basis of the success of HTR-10, HTR-PM is proposed, which aims to demonstrate the claimed inherent safety features and its economic competitiveness. The HTR-PM project will surely be benefit from the rich design and construction experiences of HTR-10. The major target of the HTR-PM Project is to build one demonstration plant of 200 MWe (Zhang and Sun, 2007). At the same time, the 10 MW high-temperature gas-cooled test reactor coupled with gas-turbine circle (HTR-10GT) has been carried out by the INET, which is considered as one of the most important development fields of the future HTR technology due to its simple system, high efficiency and potential economical competitiveness (Barnert and Kugeler, 1995).

* Corresponding author. Tel.: +86 10 62797385; fax: +86 10 62771150.
E-mail address: yanggj@tsinghua.edu.cn (G. Yang).

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In the helium blower of HTR-PM and the power convention unit (PCU) of the HTR-10GT, the mechanical bearings can't work very well for the lubricating, maintaining and replacing. The active magnetic bearing (AMB) instead of mechanical bearing will be selected to support the blower rotor or PCU rotor for their numerous advantages over the conventional mechanical bearings under the special reactor operating conditions (Gerhard et al., 1994). And the AMB doesn't require lubrication and replacement, and has become the perfect rotor supporting assembly in the reactor system (Yang et al., 2007).

In the design of AMB system, a serial of challenges must be overcome in order to ensure the reliability and stability during the reactor start up, power change and shutdown for the future engineering application, such as high temperature environment, high load-carrying capacity, high rotational speed, and so on. A lot of analysis and experiments have been carried out for AMB applied in MHTGR by the INET of Tsinghua University of China. These works will be introduced and summarized in this paper and it will offer the important theoretical base and engineering experience for the AMB applied in MHTGR.

2. Analysis of bearing system for MHTGR

2.1. Technical conditions for MHTGR bearing

The AMB will be used to support the blower rotor or PCU rotor in primary loop of HTR-PM or HTR-10GT. In order to satisfy the reactor environment and performance requirements, the following design basis of the bearings must be met.

1) High rotational speed, heavy load, and speed governing

The rotational speed for PCU rotor of HTR-10GT is 15,000 r/min. It is very high, and especially the rotor is a flexible rotor. The rotor will run through two bending mode. For the helium blower of HTR-PM, the axial load is 85,000 N, and the radial load is 19,500 N. The heavy load puts forward higher requirements on the bearing. At the same time, the bearing must adapt to changes in the rotational speed of the rotor.

2) No oil or grease lubrication

High purity helium was used as the coolant for MHTGR. The helium is strict limits for impurities. The purity of the helium will be improved for no oil or grease in the primary loop.

3) Long service life and long maintenance cycle

The service life of commercial nuclear power plant is for decades. It is very difficult for maintenance in technology, and economic loss is very big also. So the bearing life and maintenance cycle are long as far as possible.

4) Irradiation resistance and seismic requirements

The bearing works in the primary loop of the MHTGR. So it must be radiation-hardened. Bearings must be able to run under the sum of working load and earthquake load.

5) Insulation requirements

For the helium blower of HTR-PM, the shaft voltage may be produced for the manufacturing process of the generator on both ends of the rotor. If the mechanical bearing is selected to support the blower rotor, a current loop will be formed. And then the shaft current may be produced on this loop. The rotor and the mechanical bearing will be eroded. If the AMB instead of the mechanical bearing is selected to support the blower rotor, this current loop can't be formed for no contact between the rotor and AMB. So the corrosion will not appear, and the AMB can ensure the insulation.

2.2. Principle of AMB

Active magnetic bearing (AMB) is a typical mechatronics product, and it is also called electromagnetic bearing (EMB). The basic principle of the AMB is to suspend the rotor in a magnetic field by magnetic force, so the rotor can rotate without mechanical contact and wear. Compared with rolling bearings and sliding bearings, AMBs have many advantages, such as being free of contact and contaminating wear, and not requiring lubrication. The rotor can easily reach high rotational speed. It has a great future in the aerospace, nuclear industries, turbine machinery, vacuum technology, and so on.

Fig. 1 illustrates the components and function of a simple bearing. A sensor measures the displacement of the rotor from its reference position, a microprocessor as a controller derives a control signal from the measurement, a power amplifier transforms this control signal into a control current, and the control current generates the magnetic forces within the actuating magnet in such a way that the rotor remains in its hovering position. The control law is responsible for the stability of the hovering state as well as the stiffness and the damping of such a suspension (Gerhard et al., 1994).

With the development of related technologies such as mechanics, rotor dynamics, control theory, electrical technology and computer technology, the study of AMB has made corresponding progress. Theoretic analysis about AMB has evolved into an integrated system. The study of controller design and flexible rotor dynamics has been developed, and control methods are being improved effectively for controlling complicated rotors. Various algorithms of modern control theories are appearing in corresponding control software. The AMB is progressing towards multifunctional and intelligent application. However AMB applied in MHTGR will be a difficult problem. These new technologies for nuclear power station will be a challenging subject.

Abased on the above analysis, the AMB is the most appropriate bearing for MHTGR.

3. AMB applied in the helium blower of HTR-PM

3.1. Structure layout of HTR-PM

The HTR-PM nuclear power plant consists of two pebble-bed module reactors with a total thermal power of 500 MW, which

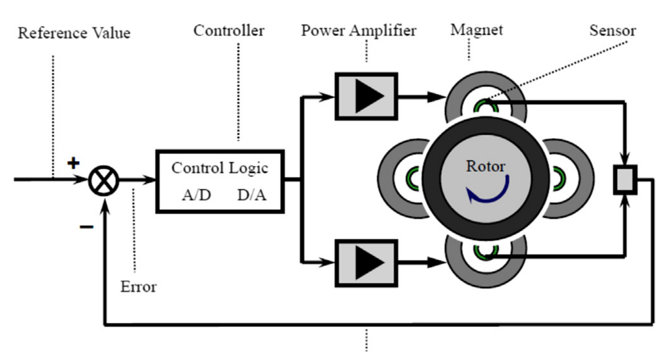

Fig. 1. AMB system working principle diagram.