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Helium blower test based on aerodynamic force simulation

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ABSTRACT

In high temperature reactor pebble-bed modules (HTR-PM), the helium blower is the key equipment which is in the primary loop and drives the helium to exchange the energy. The usage of active magnetic bearing (AMB) is to avoid the lubricating oil leaked and keep the environment of helium pure. However, helium blower test needs to proceed under the condition of helium loop, which is difficult in early construction stage and will result in much more time and money cost. In this paper, we propose and produce a new device to simulate the dynamic force to build a force environment similar to the helium loop. The device called aerodynamic force simulator (AFS) derives from the idea of active magnetic bearing and utilizes electromagnetic force replacing aerodynamic force when helium blower works. Active magnetic bearing commissioning and dropping load test of helium proceed successfully with the utilization of aerodynamic force simulator. Through a series of tests, it is proved that the aerodynamic force simulator is effective and economic, and the design of helium blower and its components is reasonable and reliable.

1. Introduction

At the end of last century, 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 is designed and built at the Institute of Nuclear and New Energy Technology of Tsinghua University of China (Xu and Zuo, 2002). Based on the success of HTR-10, the HTR-PM is currently under construction in Rongcheng, Shandong Province, China as a demonstration nuclear power plant (Zhang and Sun, 2007; Zhang et al., 2016). The HTR-PM has a design power of 200 MW, 20 times more than HTR-10, which determines its design and manufacture far more difficult.

Helium blower is the key equipment of the HTR-PM and drives the helium in the primary loop in order to exchange energy, and works at 250 °C, 7 MPa helium condition. To keep the helium environment clean and pure, AMBs are used to replace mechanical bearings. Compared to traditional bearings, there is no need to use lubricating oil due to its important characteristic of non-contact with rotor (Maslen and Schweitzer, 2009). AMB also can help the helium blower work at high speed stably under active control. The helium blower is also equipped with conventional bearings as auxiliary bearings to work when the AMB fails.

The AMB system is a typical mechatronic system that consists of electromagnet, controller, power amplifier, displacement sensors, and rotor components. Unlike traditional bearings, AMB is a closed-loop control system that can achieve stable support of the rotor by adjusting control parameters. In running process, when the position of the rotor deviates from the center position, the sensor captures the deviation as the input of the controller. The output of the controller is calculated according to proportional, integral and differential action control scheme, and is considered as a command signal for the power amplifier which has to transform this signal into the physical current flowing through the electromagnet's coil. Then the electromagnet draw the rotor back to the center position. The AMB working principle is shown in Fig. 1.

1.1. Aerodynamic characteristic of helium blower

The helium blower has special aerodynamic characteristics below which lead to the complexity of the design and test (Wang et al., 2016).

(1) The pressure rise of helium blower is designed up to 200 kPa and the diameter of impeller has even reached to 1.2 m. Hence, the aerodynamic force is much larger than that of traditional blowers and circulators.
(2) The axial AMB must endure the aerodynamic force adding the mass of rotor and motor, which demands high require-

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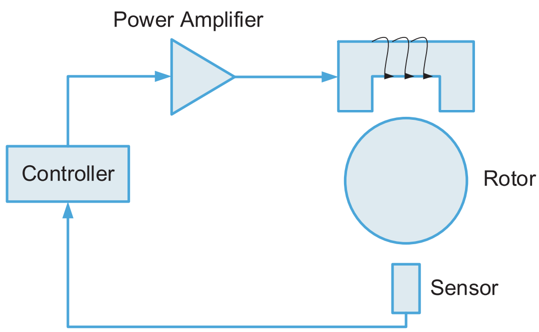

Fig. 1. The schematic diagram of AMB control strategy.

ments on the performance of AMB. Generally, the bearing capacity per unit area of AMB is much smaller than that of the mechanical bearing. Therefore, it needs aerodynamic test to verify the heavy-load AMB technology.

(3) The air gap between the rotor and AMB is about 5–10 times larger than that of mechanical bearings, which lead to enlargement of the inlet ring sealing gap and increase of the leakage flow. The pressure drops on the outer surface of impeller cover and the axial aerodynamic force also increases, which has negative effects on design, control, and safe operation of helium blower.

For the above reasons, it is necessary to test helium blower in an environment with the corresponding aerodynamic characteristics so as to verify the design and manufacture of helium blower and its components.

1.2. Difficulties of aerodynamic environment construction

It is necessary to proceed commissioning and test of helium blower under the aerodynamic environment to make the system run safely. The aerodynamic environment for helium blower test includes the helium loop and helium environment. However, there exist some difficulties to construct these working conditions before the helium blower primary tests succeed. It requires an amount of helium and will cost a lot. Generally, helium loop and helium blower are building in parallel. If helium blower integrated with helium loop is tested simultaneously, it will cost a lot of time on processing the problem of helium loop.

In summary, helium blower has complex aerodynamic characteristics, which challenges its design and verification, especially for AMB system. Therefore, helium blower should be tested and verified under the condition of aerodynamic environment. However, the establishment of aerodynamic environment and the verification of helium blower are proceed in parallel. The introduction of real aerodynamic environment will bring more problems to verification and cost a lot. It is an urgent problem to be solved in the field of nuclear engineering and requires the innovation of engineering methods.

Our research theme is to construct aerodynamic environment for aerodynamic test of helium blower under the premise of not building a helium loop. In order to fulfill the demand above, we propose and manufacture a device called aerodynamic force simulator. Inspired by AMB, AFS uses electromagnetic force instead of aerodynamic force to simulate working environment of helium blower. AFS is essentially a variation of axial active magnetic bearing and transforms the current to electromagnetic force. With the usage of AFS, AMB commissioning and rotor dropping test can be processed under the force field close to the real environment.

In this article, the introduction of helium blower is presented in Section 2. In Section 3, aerodynamic force simulator, including its structure, principle, and calibration, is detailed. Section 4 shows a series of helium blower test with AFS and finally, the conclusion is given in Section 5.

2. Helium blower

2.1. Structure of Helium blower

The main helium blower is the heart of HTM-PM. The hot helium heated in the reactor core in high temperature is driven by helium blower and transfers heat to the water in the steam generator. The water in the secondary loop becomes the high pressure superheated steam which drives the steam turbine to generate electricity. The structure layout of helium blower is shown in Fig. 2. Fig. 3 shows the engineering rig of helium blower.

AMB system used in helium blower to support the rotor consists of an axial AMB, two radial AMBs, and two auxiliary bearings. Generally, AMB works and auxiliary bearing is not active, and there exists a small gap between the rotor and auxiliary bearing. When AMB fails or the whole system operates abnormally, the auxiliary bearings will provide mechanical support for the rotational dropping rotor by its smaller endurance compared to AMB and endure huge impact force and friction heat (Yang et al., 2014a,b; Zhao et al., 2018; Zhao et al., 2016).

The main parameters of the helium blower are listed in Table 1. The rotor of the helium blower is about 3.3 meters long and 4000 kg weight. The maximal aerodynamic force is demanded to be 45000 N. The axial AMB and the upper auxiliary bearings are located at the top of the rotor, and they must bear the maximal axial load (85,000 N). The radial AMBs or the lower auxiliary bearing must bear the maximal radial load (19,500 N) respectively.

2.2. Aerodynamic load characteristics of helium blower

The purpose of this paper is to simulate the aerodynamic environment of helium blower, then it is necessary to discover the

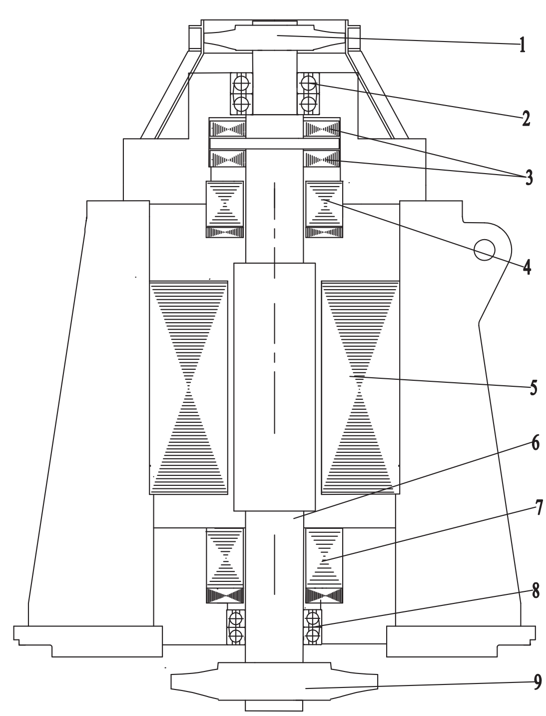

Fig. 2. Structural components of helium blower. (1) Cooling fan; (2) Upper auxiliary bearing; (3) Axial AMB; (4) Upper radial AMB; (5) Electric motor; (6) Rotor; (7) Lower radial AMB; (8) Lower auxiliary bearing; (9) Blower impeller.