Proceedings of the HTR 2014
Weihai, China, October 27-31, 2014
Paper HTR2014-41129

Design and Experiment of Auxiliary Bearing for Helium Blower of HTR-PM

YANG Guojun[1], SHI Zhengang[1], LIU Xingnan[1], ZHAO Jingjing[1]
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.
phone: +86-10-80194001, yanggj@tsinghua.edu.cn

Abstract – *The helium blower is the important equipment for HTR-PM. Active magnetic bearing (AMB) instead of mechanical bearing is selected to support the rotor of the helium blower. However, one implication of AMB is the requirement to provide the auxiliary bearing to mitigate the effects of failures or overload conditions. The auxiliary bearing is used to support the rotor when the AMB fails to work. It must support the dropping rotor and bear the great impact force and friction heat. The design of the auxiliary bearing is one of the challenging problems in the whole system. It is very important for the helium blower with AMB of HTR-PM to make success. The rotor's length of helium blower of HTR-PM is about 3.3 m, its weight is about 4000 kg and the rotating speed is 4000 r/min. The axial load is 4500kg, and the radial load is 1950kg. The angular contact ball bearing was selected as the auxiliary bearing. The test rig has been finished. It is difficult to analyze the falling course of the rotor. The preliminary analysis of the dropping rotor was done in the special condition. The impact force of auxiliary bearing was computed for the axial and radial load. And the dropping test of the blower rotor for HTR-10 will be introduced also in this paper. Results offer the important theoretical base for the protector design of the helium blower with AMB for HTR-PM.*

I. INTRODUCTION

High-temperature gas-cooled reactor-pebble bed module (HTR-PM) of China, based on the technology and experience of the 10MW high-temperature gas-cooled reactor (HTR-10), is currently in the mechanical processing and test phase. The helium blower is the key equipment in the primary loop of the HTR-PM. It makes the helium flow around the HTR-PM.

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 for their numerous advantages over the conventional mechanical bearings under the special reactor operating conditions[1]. And the AMB doesn't require lubrication and replacement, and has become the perfect rotor supporting assembly in the reactor system[2].

The auxiliary bearing will be applied in the AMB system as the backup protector when the AMB fails to work. The auxiliary bearing located at the outer-bound of the AMB is also called a catching bearing or a back-up bearing. Being assembled on the stator, the auxiliary bearing does not work during the normal operation of the magnetic bearing. The clearance of the auxiliary bearing is smaller than that of the magnetic bearing. Typically, fifty percent of the magnetic bearing clearance is used for the auxiliary bearing clearance.

The use of rolling element bearing with grease lubrication as auxiliary bearing is widespread in rotating machinery incorporates magnetic bearing. The function of the auxiliary bearing is to prevent rotor/stator contact, for which the inner race can experience a high impact force and rapid angular acceleration. Rapid deterioration of the auxiliary bearing can result from rotor impacts and high-speed touchdowns. It is therefore important to ascertain the influence of auxiliary bearing design parameters on the number of touchdowns that can be tolerated before replacement is required. A prerequisite is to understand the dynamic behavior of the system during a touchdown event, and this is also a necessary step before attempting to predict any thermal transients within the auxiliary bearing[3].

The angular contact ball bearing is selected as the auxiliary bearing. The bearing model is 71938. It is used in pairs. Each pair of bearings is applied in face to face. Two pairs of bearings lie in upper rotor and lower rotor respectively. It is the ceramic bearing without lubrication.

The auxiliary bearings must bear the impact force and friction of the dropping rotor when the AMB fails to work at the high speed.

The dropping test for blower rotor of HTR-PM and HTR-10 has already been done, the impact force of the auxiliary bearing will be analyzed, and the friction heat of this bearing will also be discussed in this paper. Results will offer the basis for the application of this auxiliary bearing in special environment.

II. STRUCTURE OUTLINE OF HELIUM BLOWER

The HTR-PM nuclear power plant consists of two pebble-bed module reactors with a total thermal power of 450 MW, which connect to one steam-turbine generator. Each reactor module basically comprises a reactor pressure vessel (RPV), a steam generator pressure vessel (SGPV), and a connecting horizontal coaxial hot-gas duct pressure vessel (HDPV) as well as their internal components. The RPV and the SGPV are installed in their own concrete shielding cavities, respectively. The main helium blower is mounted on the upper part of the SGPV. The hot helium with an average temperature of 750℃, heated in the reactor core, transfers heat to the secondary loop water in the steam generator to produce high pressure superheated steam, which drives the steam turbine to generate electricity. The cross-section of the reactor is shown in Fig.1[4].

Helium blower is used to drive helium to flow in the first loop. The helium pressure is 7 MPa, and the helium mass flow rate is 96 kg/s. The electric motor's power is 4500kw. The structure components of the helium blower are shown in Fig.2.

AMB will be used to support the rotor. The axial AMB is in the top of the rotor, and it must bear the maximal axial load (8500kg). The upper or lower radial AMB must bear the maximal radial load (1950kg), respectively.

When the rotor is not supported by AMB, the auxiliary bearing will be used to support rotor. The upper auxiliary bearing can support the rotor in axial and radial direction. The lower auxiliary bearing can only support the rotor in radial direction.

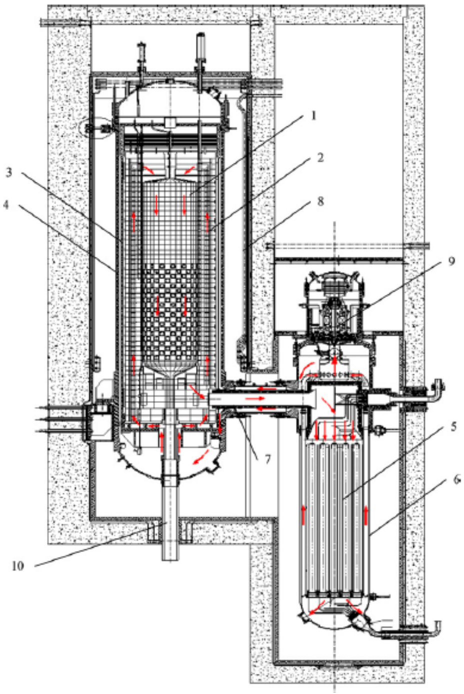

Fig. 1. Cross section of the primary circuit of the HTR-PM. 1, reactor core; 2, side reflector and carbon thermal shield; 3, core barrel; 4, reactor pressure vessel; 5, steam generator; 6, steam generator vessel; 7, coaxial gas duct; 8, water-cooling panel; 9, blower; 10, fuel discharging tube

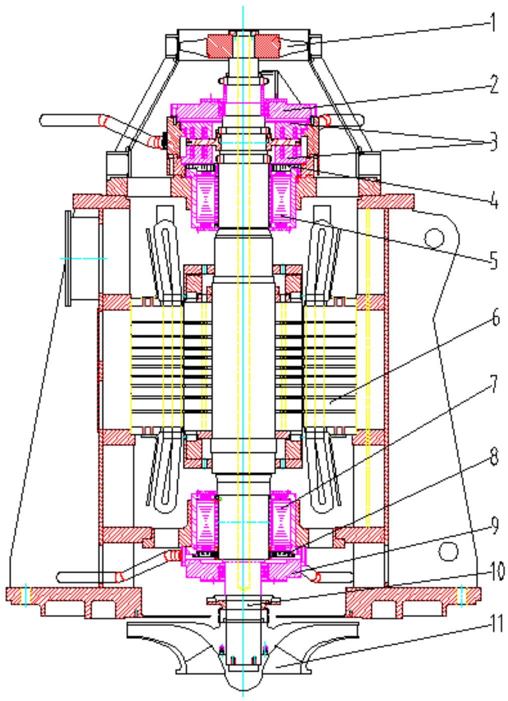

Fig. 2. Structural components of the blower. 1, cooling fan; 2, upper auxiliary bearing; 3, axial AMB; 4, upper position sensor; 5, upper radial AMB; 6, electric motor; 7, lower radial AMB; 8, lower position sensor; 9, lower auxiliary bearing; 10, rotor; 11, blower wheel

III. DROPPING TEST OF HTR-PM ROTOR

The operating procedures of the dropping experiment are as follows. When the rotor is running at 3000r/min steadily, the power is cut off suddenly, and the rotor can't be supported by AMB, and will touch down to the auxiliary bearing. The frequency converter has the brake and the speed of the dropping rotor will stop in 10s.

Fig.3 shows the axial displacement curve of the dropping rotor. Zero point of the ordinate is the static levitation position. The dropping distance is 0.3mm. That is the distance between the rotor and auxiliary bearing. The dropping rotor will touch down the auxiliary bearing after 0.5ms. The vibration will tend to be stable after 1ms.

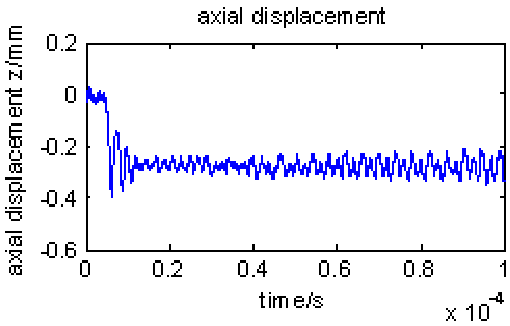

Fig.3 Axial displacement curve of the rotor.

The experimental results show the auxiliary bearing can bear the impact force and fiction heating. But the load and revolving speed is not large. So this is just a preliminary dropping experiment. It offers the important basis for the dropping experiment in the helium loop.

IV. DROPPING TEST OF HTR-10 ROTOR

The rolling element bearing with grease lubrication was selected to support the rotor of the helium blower of HTR-10.

However, this bearing can't be used in the commercial reactor for replacement and lubrication. The replacement is difficult for the radiation, and the lubricant will pollute the reactor. So the AMB will become the new supporting system in the helium blower of HTR-10. The auxiliary bearing will be applied in the AMB system as the backup protector.

The AMB has been designed for helium blower. The rig has been built for research. The figure 4 shows the structure and picture of the helium blower rig. The parameters are listed in Table 1.

Table 1: Parameters of helium blower

Parameter	Value
Mass of rotor	450kg.
Length of rotor	1518mm
Distance between two radial AMB	800mm
Axial moment of inertia	7.9kg•m^2
Transverse moment of inertia	78kg•m^2
Radial gap between rotor and auxiliary bearing	0.18mm
Axial gap between rotor and auxiliary bearing	0.52mm
Axial load	180kg
Rotating speed	5000r/min

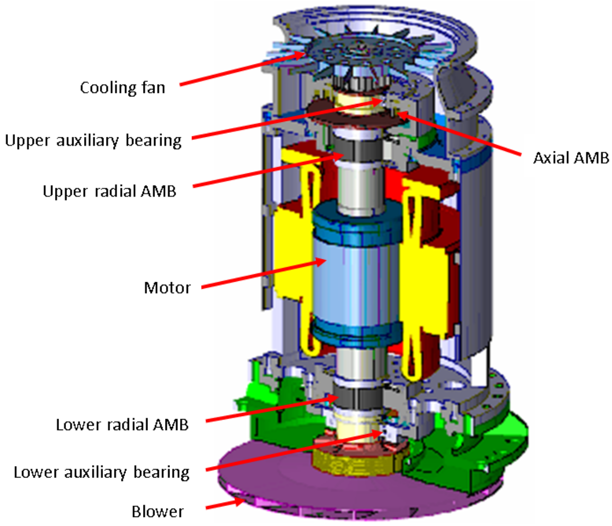

Figure 4. The structure and picture of the helium blower rig

IV.A. ANALYSIS OF IMPACT LOAD

The normal rotating speed of the rotor is 5000r/min. If the AMB fails to work under this speed, the rotor will fall off suddenly to the auxiliary bearing. The auxiliary bearing must support the dropping rotor, and can bear the great impact load and friction heat. So the auxiliary bearing will fail to work because the impact load and friction heat.

The dropping test is very dangerous for the rotor and AMB system, so theoretical analysis may be done at first. And then the dropping test will be carried out from lower rotating speed to higher rotating speed. The maximum impact force and friction will be produced at the maximum dropping rotating speed (5000 r/min). But the theoretical analysis is difficult for the complex of the dropping course. The test results will be true. So the test results will be introduced in this section.

Figure 5 and 6 are the axial displacement curve and axial impact force curve at the maximum dropping rotating.

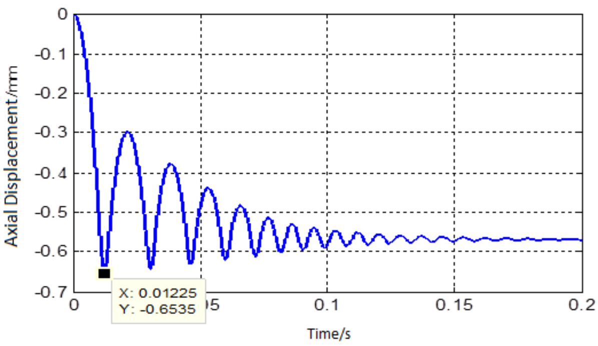

Figure 5. Axial displacement curve of the dropping rotor

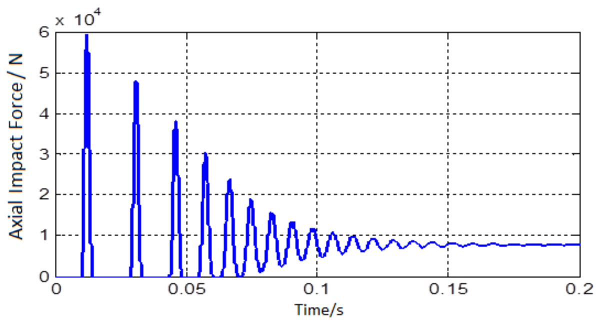

Figure 6. Axial impact force curve of the dropping rotor

The maximum displacement of the auxiliary bearing is 0.134mm from Figure 5, and the maximum axial impact force is 60 kN from Figure 6.

Figure 7 is the radial impact force curve at the maximum dropping rotating speed. The maximum radial impact force is 20 kN from Figure 7.

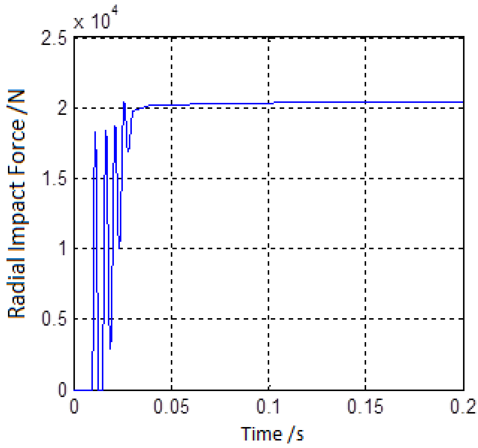

Figure 7. Radial impact force curve of the dropping rotor

V. CONCLUSION

The design and experiment of the auxiliary bearing for HTR-PM and HTR-10 has been introduced in this paper.

But this is the preliminary results. Further experiments and analysis will be done in the future. For example, the dropping test in the helium and auxiliary bearing evaluation standard analysis, etc.

ACKNOWLEDGMENTS

This paper is jointly supported by the National Natural Science Foundation of China (No. 51275261) and National S&T Major Project (No. ZX069).

REFERENCES

[1] Gerhard, S., Hannes, B., Alfons, T., 1994. Active Magnetic Bearings. Vdf Hochschulverlag AG an der Eth Zurich, 244.
[2] Yang Guojun, Xu Yang, Shi Zhengang, Gu Huidong. Characteristic analysis of rotor dynamics and experiments of active magnetic bearing for HTR-10GT. Nuclear Engineering and Design. 2007(237): 1363-1371.
[3] Yang Guojun, Shi Zhengang, Zhao Jingxiong, Yu Suyuan. RELIABILITY ANALYSIS OF HELIUM BLOWER AUXILIARY BEARINGS FOR HTR-10. San Francisco, American. 22nd International Structural Mechanics in Reactor Technology (SMiRT-22). August 18-23, 2013: 2912-2916
[4] Yanhua Zheng, J. Lapins, E. Laurien, L. Shi, Z. Zhang. Thermal hydraulic analysis of a pebble-bed modular high temperature gas-cooled reactor with ATTICA3D and THERMIX codes. Nuclear Engineering and Design. 2012(246): 286-297.