Research and Experiment of Auxiliary Bearings with No Lubrication for Helium Blower of HTR-10

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Abstract— **The auxiliary bearing is one of the important parts for the active magnetic bearing (AMB). A new auxiliary bearing design with no lubrication is proposed in this paper. This auxiliary bearing is composed of angular contact ceramic ball bearing. Two pairs of bearing will be distributed on both ends of the rotor. Each pair of bearing arrangement is face to face. Oil or grease will not be applied in this auxiliary bearing. But dry lubrication with MoS_2 will be used in this bearing. This auxiliary bearing will be applied in the helium blower of 10MW high-temperature gas-cooled reactor (HTR-10). Oil or grease can't be used in the primary loop of the HTR-10. The auxiliary bearing is used to support the blower rotor when the AMB fails to work. It must support the dropping rotor and bear the great impact force and friction heat. It is difficult to analyze the falling course of the rotor. There are two difficult problems to solve for the design of auxiliary bearing, including great impact force and friction heat. The preliminary analysis of the rotor was done. The impact force of the auxiliary bearing was computed for the axial and radial impact load by the finite element method. The temperature field will be analyzed and studied also in this paper. The auxiliary bearing's life will be evaluated. The scheme of auxiliary bearing and the simulation results offer the important theoretical base for this new auxiliary bearing style, and offer the protector design of the helium blower with AMB for HTR-10.**

A. Introduction

A 10MW high-temperature gas-cooled test reactor (HTR-10) was constructed by the Institute of Nuclear and New Energy Technology (INET) at Tsinghua University of China. It has been operated to generate electricity on January, 2003. The helium blower is the key equipment in the primary loop of THR-10. It makes the helium flow around the HTR-10. The rolling element bearing with grease lubrication was selected to support the rotor of the helium blower.

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 Active Magnetic Bearing (AMB) can overcome these shortcomings, and the AMB instead of mechanical bearing will become the new supporting system in the helium blower. The auxiliary bearing will be applied in the AMB system as the backup protector[1].

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[2-3].

A new auxiliary bearing design with no lubrication will be introduced in this paper. The angular contact ceramic ball bearing will be used as auxiliary bearing. Two pairs of angle contact ball bearing will be distributed on both ends of the rotor. Each pair of bearing arrangement is face to face. Oil or grease will not be applied in this auxiliary bearing. But dry lubrication with MoS_2 will be used in this bearing.

This auxiliary bearing will be applied in the helium blower of 10MW high-temperature gas-cooled reactor (HTR-10). But, so far, this bearing with no lubricate applied in the high temperature reactor is a very difficult problem.

Some dropping tests for rotor have 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.

B. THE HELIUM BLOWER RIG WITH AMB

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

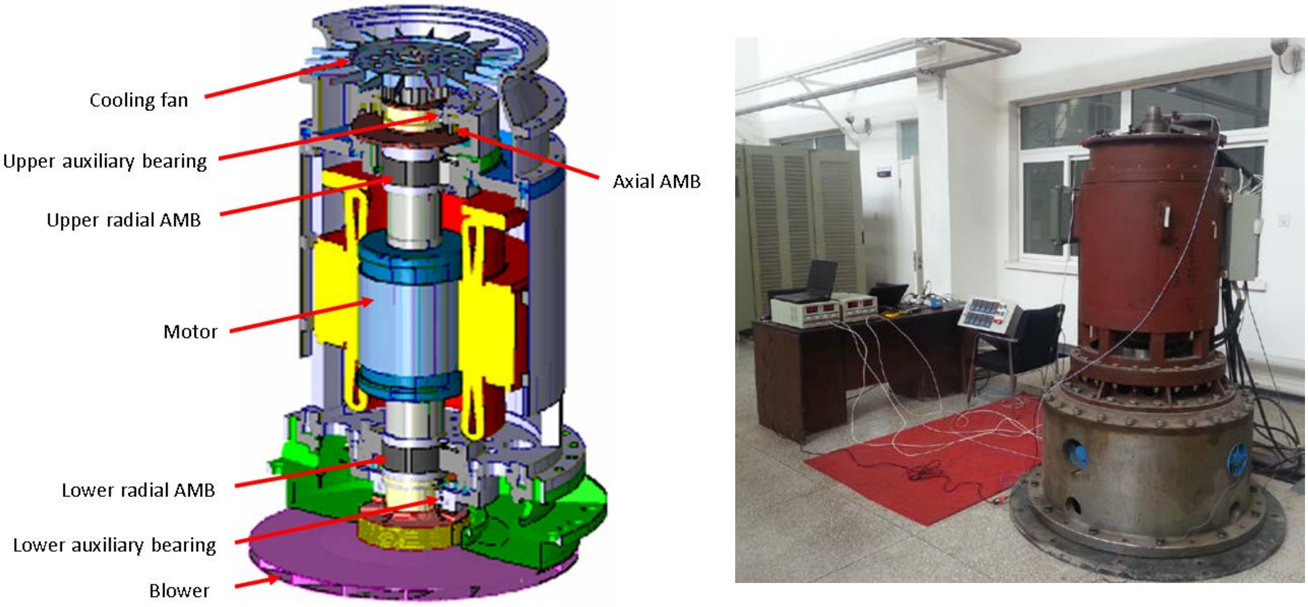


Figure 1. The structure and picture of the helium blower rig

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

The angle contact ball bearing is applied as the auxiliary bearing for helium blower with AMB. The model is 71926ACD. It is the ceramic bearing with dry lubrication instead of oil or grease. The outer ring and the inner ring are designed by special way.

Two pairs of angle contact ball bearing will be distributed on both ends of the rotor. Each pair of bearing arrangement is face to face. The upper auxiliary bearing carries the radial and axial load, and the lower auxiliary bearing carries the radial load.

The material of bearing rings is bearing steel, and the rolling element is ceramic ball. The material of the cage is ployimide.

The parameters of bearing rings are as followed. Young's modulus is 1.99 × 105MPa, Poisson's ratio is 0.269, the yielding limit is 1600MPa[4]. The parameters of ceramic ball are as followed. Young's modulus is 3.15 × 105MPa, Poisson's ratio is 0.3[5], the strength limit is 3500 MPa[4].

C. IMPACT LOAD OF DROPPING ROTOR

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 2 and 3 are the axial displacement curve and axial impact force curve at the maximum dropping rotating.

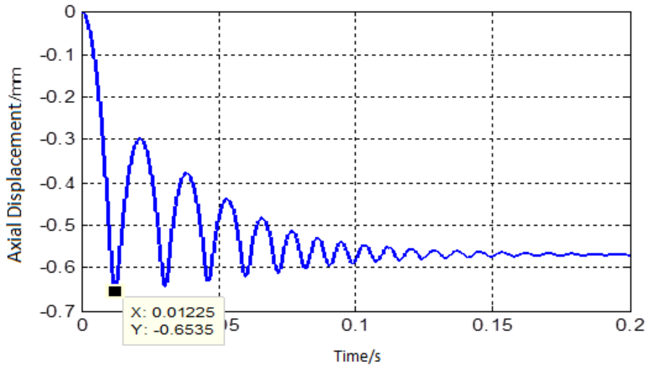


Figure 2. Axial displacement curve of the dropping rotor

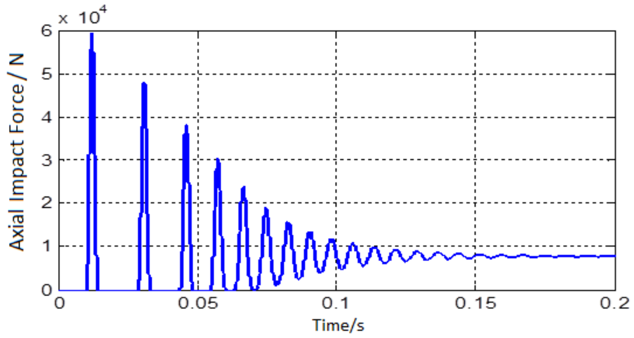


Figure 3. Axial impact force curve of the dropping rotor

The maximum displacement of the auxiliary bearing is 0.134mm from Figure 2, and the maximum axial impact force is 60 kN from Figure 3.

Figure 4 and 5 are the angle velocity curve of the rotor and radial impact force curve at the maximum dropping rotating speed.

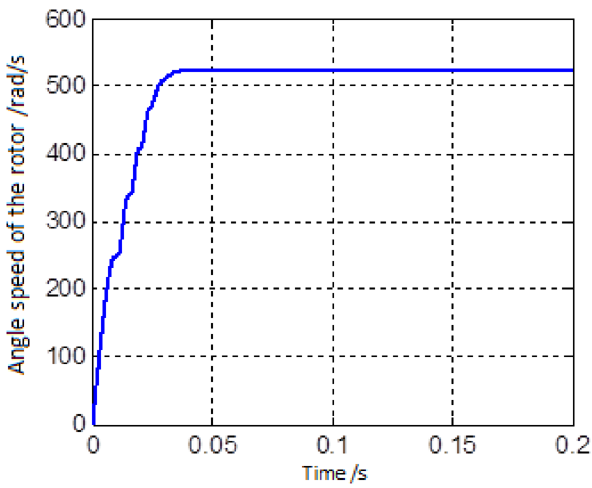


Figure 4. Radial displacement curve of the dropping rotor

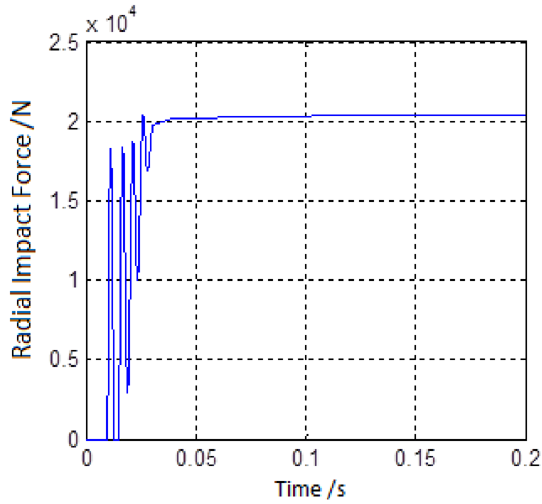


Figure 5. Radial impact force curve of the dropping rotor

The maximum angle velocity of the rotor is 521rad/s from Figure 4, and the maximum radial impact force is 20 kN from Figure 5.

The radial equivalent static load is:

$$P_r=F_r+0.76*F_a=20+0.76*60=65.6 \text{ kN}$$

The basic static load rating P_{or} of the auxiliary bearing is 110.9 kN. P_{or} is bigger than the P_r. So this auxiliary bearing can bear the impact force of the dropping rotor.

D. FRICTION HEAT OF AUXILIARY BEARING

When the rotor with high rotating speed falls to the auxiliary bearing, the bearing will produce great heat energy in a short time. The auxiliary bearing may be burned by the heat energy. So the analysis of friction heat is very important.

However the friction is very complicated. A simple simulation was completed by the finite element method in this paper. The initial temperature is supposed to be 20℃. But the time is very short for the first impact time, and the friction heat is not clearly. The temperature of the auxiliary bearing improves only 6.9℃. The temperature field is showed in figure 6. In fact, the friction heat may be very high in a short period of time because of the high rotating speed, full load and enclosed environment. But the temperature rises very little in this paper. The reason is on the light load or good heat dissipation.

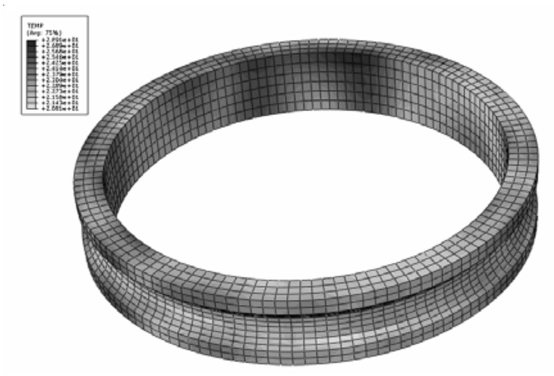
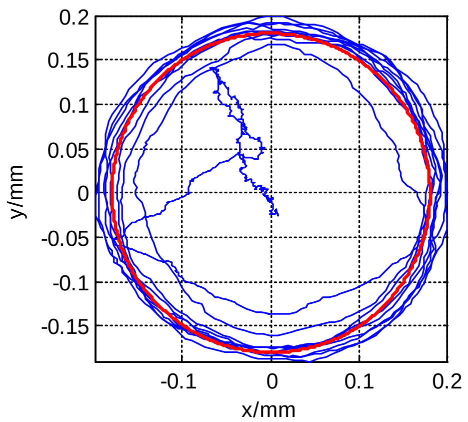


Figure 6. The temperature field analysis of the inner ring

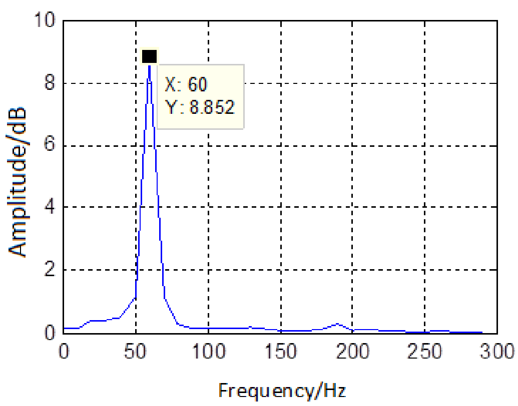
E. DROPPING TEST OF DIFFERENCE ROTATING SPEED

It has different influence for auxiliary bearing at different dropping speed. So some dropping tests have been done to study rotor dropping dynamics for different dripping speed.

Figure 7, 8, 9 and 10 give the result of axis trajectory and spectrum of radial displacement at 60Hz, 40Hz, 35Hz and 25Hz.

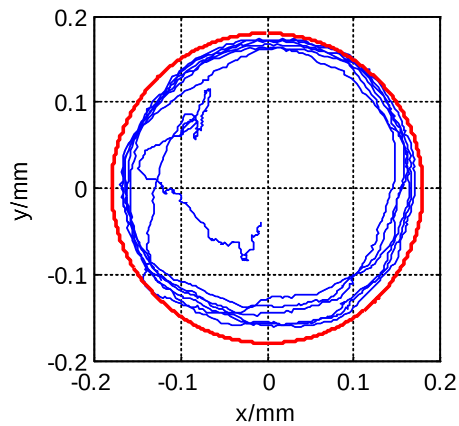


a) axis trajectory

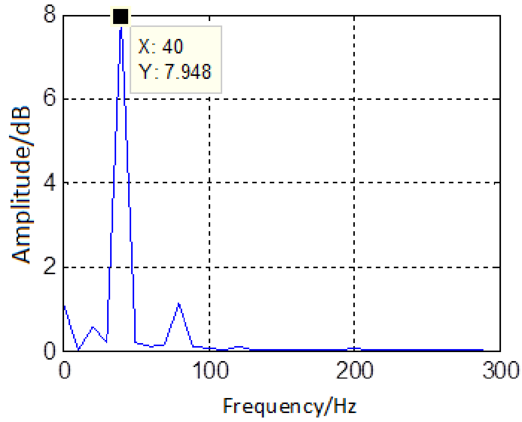


b) spectrum of radial displacement

Figure 7. Axis trajectory and spectrum at 60Hz

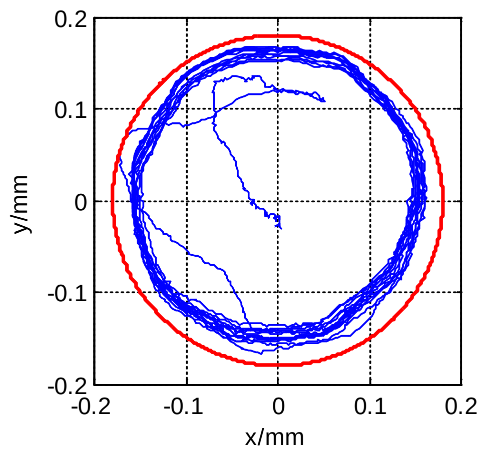


a) axis trajectory

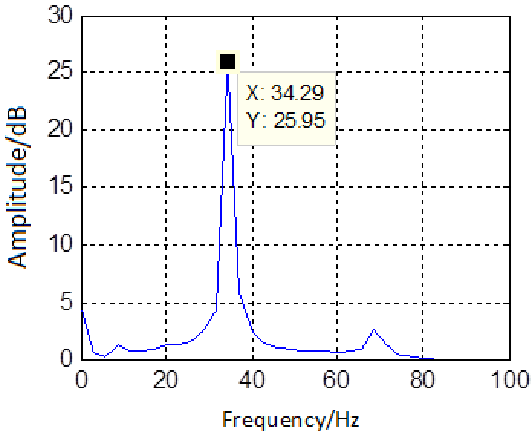


b) spectrum of radial displacement

Figure 8. Axis trajectory and spectrum at 40Hz

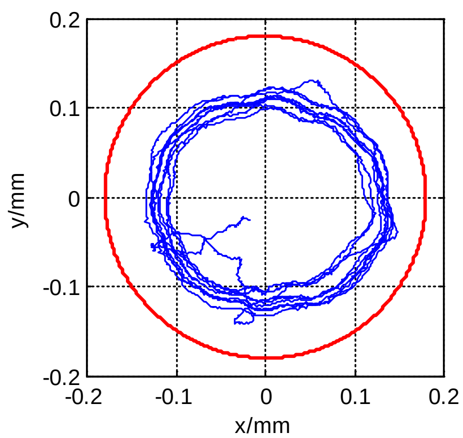


a) axis trajectory

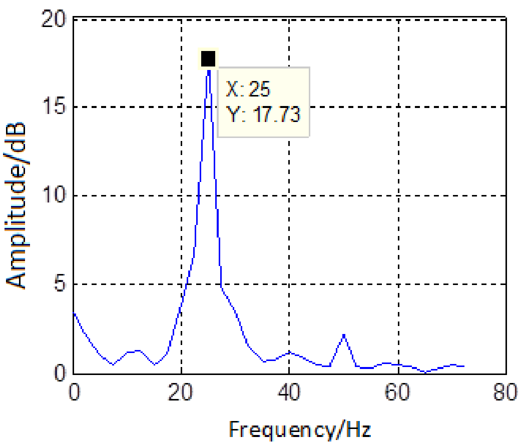


b) spectrum of radial displacement

Figure 9. Axis trajectory and spectrum at 35Hz



a) axis trajectory



b) spectrum of radial displacement

Figure 10. Axis trajectory and spectrum at 25Hz

From the above figures, we can know that the rotor rotates around the axis with the reduction of the rotating speed, and the rotor don't touch the inner ring of the auxiliary bearing or the radial impact force will reduce little by little.

That is to say, the axial impact force will turn small with the reduction of the rotating speed. The axial impact force can influence the radial motion of the rotor because the generating of the cross-couple stiffness is mainly by the friction force at the thrust interface of the auxiliary bearing. So the reduction of the axial force may reduce the friction force. Then it may have positive effect on the decrease the forward whirl of the rotor. However, because such process is complicated, the relationship between the axial force and the cross-couple stiffness still need further research.

F. Conclusion

A new auxiliary bearing style is proposed in this paper. It is applied in the helium blower of HTR-10. The experiments of AMB and auxiliary bearing are implementing. The impact load and temperature field have been analyzed by the finite element method in this paper.

The drop process can be divided into 3 steps. The first step is the free fall process. The second step is the bounces and backward whirl period. The third part is the forward whirl period. The preliminary analysis has been done. The impact force is about 60kN (instant peak). The friction heat is not so high.

But this is the preliminary results. Further experiments and analysis have been designed. It will be done in the future time. For example, the dropping test in the helium and auxiliary bearing evaluation standard analysis, etc. These results will be introduced in the future paper.

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