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Research and experiment of auxiliary bearing for helium circulator of HTR-PM

Guojun YANG, Zhengang SHI, Jingjing ZHAO, Yan ZHOU, Xingnan LIU, Ni MO, Zhe SUN
Institute of Nuclear and New Energy Technology of Tsinghua University, Collaborative Innovation Center of Advanced Nuclear Energy Technology, the Key Laboratory of Advanced Reactor Engineering and Safety, Ministry of Education, Beijing, China, 100084
E-mail: yanggj@tsinghua.edu.cn

Abstract
The research and application of the unlubricated auxiliary bearing is very important in certain special circumstances, such as in the nuclear power station, aeroplane engine and so on. Active magnetic bearing (AMB) is replacing ordinary mechanical bearings as the perfect supporting scheme for the helium circulator of high-temperature gas-cooled reactor-pebble bed module (HTR-PM) of China. Because it has several advantages: free of contact, no lubrication and controllability very well, etc. The auxiliary bearing is used to support the circulator rotor when the AMB fails to work, but oil or grease can't be applied for this auxiliary bearing. And 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. A new design plan of auxiliary bearing is proposed in this paper. This auxiliary bearing is composed of angular contact ceramic ball bearing designed by special technology. Two pairs of bearing will be distributed on both ends of the rotor. Each pair of bearing arrangement is face to face. The rotor's length of helium circulator of HTR-PM is about 3.3 m, its weight is about 4000 kg and the rotating speed is 4000 r/min. It is difficult to analyze the falling course of the rotor. The preliminary analysis and experiment of the dropping rotor was done in this paper. The auxiliary bearing's life will be evaluated. And the buffer shim is also studied to reduce the impact force by simulation in this paper. The scheme of auxiliary bearing and the experimental results offer the important base for this new auxiliary bearing style, and offer the protector design of the helium circulator with AMB for HTR-PM.

Keywords : Active Magnetic Bearing, Auxiliary Bearing, Touch Down, Helium Circulator, HTR-PM

1. Introduction

The high temperature gas-cooled reactor pebble-bed modular (HTR-PM) of China is a 200MW nuclear power station. The helium circulator is the key equipment in the primary loop of 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 circulator rotor for their numerous advantages over the conventional mechanical bearings under the special reactor operating conditions, (Guojun YANG, et al., 2014). And the AMB doesn't require lubrication and replacement, and has become the perfect rotor supporting assembly in the reactor system. The auxiliary bearing will be applied in the system as the backup protector, (YANG Guojun, et al., 2007).

The auxiliary bearing located at the outer-bound of the AMB is also called a catcher bearing or a back-up bearing. Being assembled on the stator, the auxiliary bearing is not active during the normal operation of the AMB. The clearance of the auxiliary bearing is smaller than that of the AMB to protect it, (Gerhard Schweitzer, 1994). When the AMB fails to work, the auxiliary bearing must support the dropping rotor and can bear the great impact force and fiction heating. So the auxiliary bearing is the important safety guarantee for the whole rotor system.

The use of rolling element bearing for auxiliary bearing is widespread in rotating machinery incorporates magnetic bearing. A new design method of auxiliary bearing will be introduced in this paper. 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 bearing lie in upper rotor and lower rotor respectively. It is the ceramic bearing without lubrication. The bearing rings and cage are designed by special technology.

This auxiliary bearing has been used in the helium circulator of HTR-PM. The preliminary analysis and experiments has been done. And the simulation on buffer shim is also been done to reduce the impact force. These results will be analyzed in this paper. Moreover, it is also offer the important foundation for the following work on the research of auxiliary bearing.

2. Helium circulator rig and auxiliary bearing design

The AMB has been designed for helium circulator. The rig has been built for research. The figure 1 shows the helium circulator rig. The parameters are listed in Table 1.

Fig.1 The test rig of helium circulator of HTR-PM

Table 1: Parameters of helium circulator of HTR-PM

Parameter	Value
Mass of rotor	4000kg (Prototype rotor) 2700kg (Test rotor)
Length of rotor	3.3m
Distance between two radial AMB	1.6m
Distance between two auxiliary bearings	2.4m
Radial gap between rotor and auxiliary bearing	0.3mm
Axial gap between rotor and auxiliary bearing	0.3mm
Rotate speed	4000r/min
Axial load	4500kg
Radial load	2000kg

The angle contact ball bearings designed by special technology are applied as the auxiliary bearing for helium circulator with AMB. The model is 71938ACD. The upper auxiliary bearing carries the radial and axial load, and the lower auxiliary bearing carries the radial load.

3. Dropping experiment for test rotor

The normal rotating speed of the rotor is 4000r/min. The working load is 8500kg. 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 fiction heat. So the auxiliary bearing may be broken for the impact load and fiction heat.

The auxiliary bearings have been produced by special technology for the heavy load. It is very difficult to analyze the dropping process. However, it is a very important problem for the system safe. So some dropping experiments have been carried out.

Some experiments were done step by step for the system safe. The experiment on 3000r/min with no aerodynamic load was done in the first place. The test rotor (2700kg) was used in the first experiment.

And the full speed dropping experiment will be done after summarizing the data for the experiments on 3000r/min.

The dropping experiment on 3000r/min has been finished. The results will be analyzed in the following paper.

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. Some data will be recorded in this course.

The changing curve of radial and axial displacement is in figure 2 after the power was shut up. We can know that maximum displacement is bigger than design valve (0.3mm) from figure 2. It explains that the elastic deformation was occurred for auxiliary bearings.

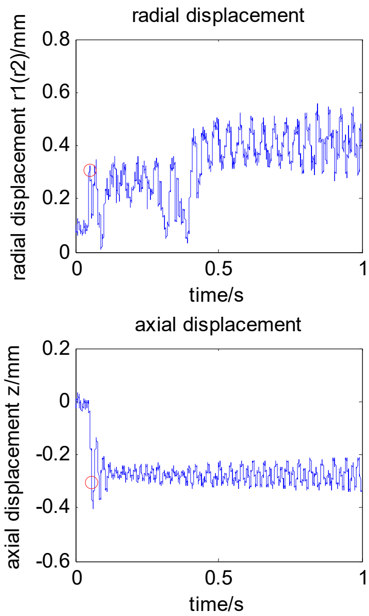

Fig 2. The changing curve of radial and axial displacement

The dropping speed curve is shown in figure 3. The sampling frequency is 10k. So the touching time is as following: (209-170)*0.0001=0.0039s

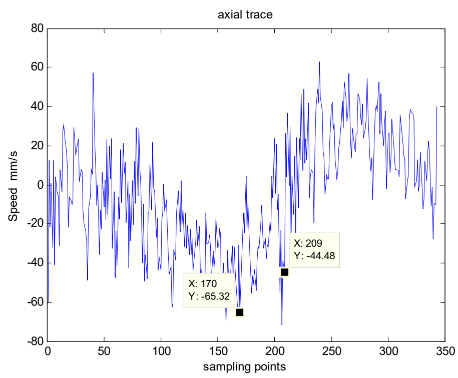

Fig.3 The dropping speed curve

From figure 3, we can know the touching speed (v_1) is -65.32mm/s, and leaving speed (v_2) is -44.48mm/s. Then the impact force can be computed by the momentum theorem as following:

$F=(mv_2-mv_1)/t$

$=2700*(44.48+65.32)*0.001/0.0039=76015N$

But this is the preliminary results. The following dropping experiment for prototype rotor has been designed. But the running experiments for the circulator have not finished yet. Because of the dangerous for the dropping experiment, the dropping experiment for the prototype rotor must be the last experiment. It may be carried out in the near future.

4. Research on the buffer shim

From the above paper, we can know the impact load is very huge. Auxiliary bearing will bear huge instantaneous impact load when the AMB fails to work in the helium circulator. The huge load may cause serious damage to the auxiliary bearing. In order to reduce the impact load and protect the AMB and rotor system, a new type of buffer shim has been designed. The small test rig has been established for the research on the rotor drop in Fig4. And the main parameters are shown in the Table 2.

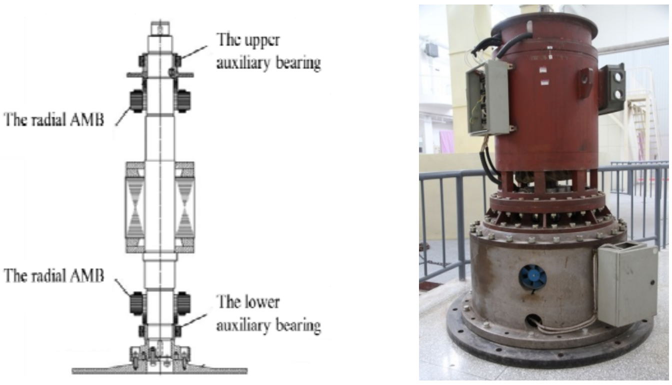

Fig.4 The structure of the small test rig

Table.2 The main parameters of the bearing system

Parameters	Value
Total mass	440kg
Total length	1518mm
Average diameter	130mm
Running speed	5000r/min
Axial clearance between the auxiliary bearing and rotor	0.52mm
Radial clearance between the auxiliary bearing and rotor	0.18mm

Figure 5 shows the structure of the upper auxiliary bearing. The buffer shim is arranged between the bottom of the outer race and the bearing seat, with a thickness of 5mm. On the choice of buffer shim, it is made of the flexible graphite. It has a good compression back and high strength, and has an extremely strong pressure resistance, high temperature resistance and good sealing characteristics, which can ensure the air tightness of the experimental apparatus.

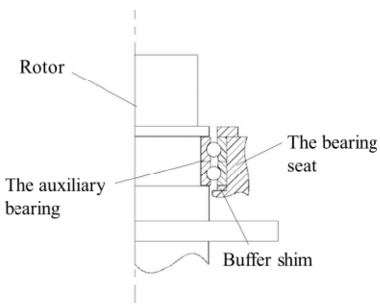

Fig.5 The structure diagram of the auxiliary bearing and buffer shim

Some results have been received by simulation. According to the Fig. 6, there are 6 collisions occurred in the initial 100ms in the both two structures of the auxiliary bearing, with or without the buffer shim. When the buffer shim is added to the auxiliary bearing, it can be found that the average contact time between the rotor and the auxiliary bearing has increased from 2.4ms to 2.9ms. Besides, the maximum bounce height of the rotor has decreased from 0.392mm to 0.322mm. However, the maximum dropping height of the rotor has increased from 0.643mm to 0.695mm due to the loss of integral rigidity of the auxiliary bearing, which is occurring in the first collision. But the added dropping height is still less than the axial gap of the AMB and rotor, and it will not cause any effect to the AMB.

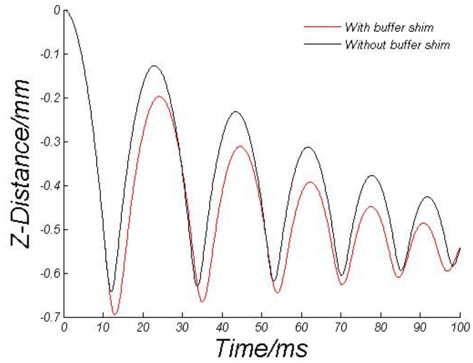

Fig.6 The rotor dropping trajectory

The inner race of the auxiliary bearing will bear the direct impact of the rotor, and the outer race is contact with the bearing seat, which will affect the stability of the whole structure, so it is also important to analyze the stress distribution of the inner and outer race of the auxiliary bearing. Fig.7 and 8 show the stress distribution of the inner race when the stress is peak during the first impact. The figures illustrate that the main stress of the inner auxiliary bearing occurs in the upper and lower part of the auxiliary bearing, while the maximum stress still occurs in the connection of the ceramic ball and inner race in the auxiliary bearing. Besides, the maximum stress of the inner race is also reduced from 184MPa to 152MPa by adding the buffer shim.

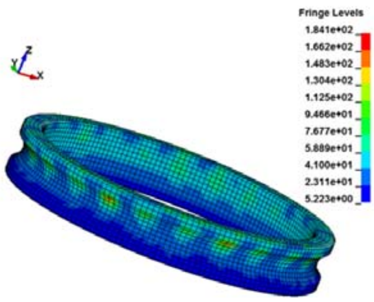

Fig.7 The stress distribution of the inner race dropping without buffer shim

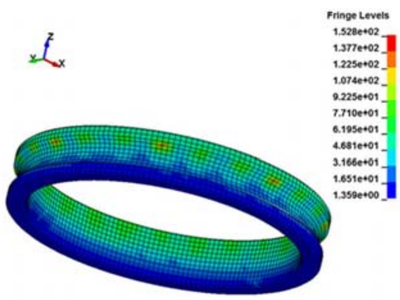

Fig.8 The stress distribution of the inner race dropping with buffer shim

Fig.9 and 10 show the stress distribution of the outer race when the stress is peak during the first impact. Both the figures illustrate the maximum stress of the outer race also occurs in the connection of the ceramic ball and outer race, which is far more than other parts of the stress. Due to the addition of the buffer shim, the maximum stress also has a big reduce from 225MPa to 180MPa.

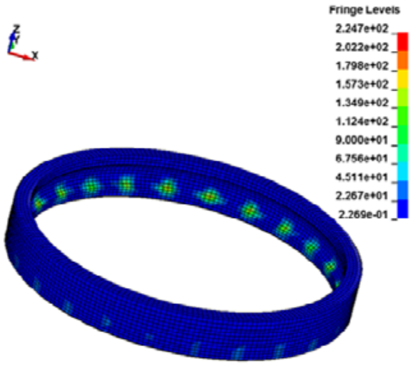

Fig.9 The stress distribution of the outer race dropping without buffer shim

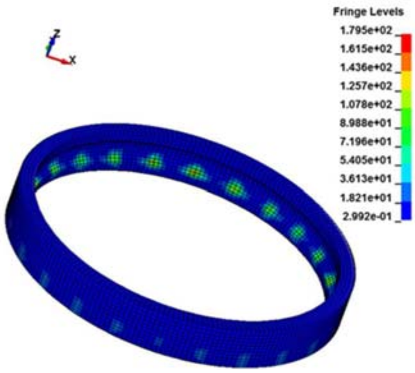

Fig.10 The stress distribution of the outer race dropping with buffer shim

So the results show the buffer shim can effectively increase the average contact time between the rotor and the auxiliary bearing and reduce the bounce height of the rotor, which also decreases the stress distribution of the auxiliary bearing to ensure the safety of the structure when rotor is falling. It offers the basis for the buffer shim applying in the helium circulator of HTR-PM.

5. Conclusion

A new auxiliary bearing style made by special technology is proposed in this paper. It is applied in the helium circulator of HTR-PM. The preliminary dropping experiment of auxiliary bearing has been implemented for the test rotor. The experimental results show this auxiliary bearing can bear the impact force and fiction heating. The buffer shim is also studied in a small test rig. Results will be applied in the helium circulator of HTR-PM. But this is the preliminary results. The following dropping experiment for prototype rotor has been designed. It will be done in following time.

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