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AUXILIARY BEARING DESIGN AND ROTOR DYNAMICS ANALYSIS OF BLOWER FAN FOR HTR-10

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ABSTRACT

The electromagnetic bearing instead of ordinary mechanical bearing was chosen to support the rotor in the blower fan system with helium of 10MW high temperature gas-cooled test reactor (HTR-10), and the auxiliary bearing was applied in the HTR-10 as the backup protector. When the electromagnetic bearing doesn't work suddenly for the power broken, the auxiliary bearing is used to support the falling rotor with high rotating speed. The rotor system will be protected by the auxiliary bearing. The design of auxiliary bearing is the ultimate safeguard for the system. This rotor is vertically mounted to hold the blower fan. The rotor's length is about 1.5 m, its weight is about 240 kg and the rotating speed is about 5400 r/min. Auxiliary bearing design and rotor dynamics analysis are very important for the design of blower fan to make success. The research status of the auxiliary bearing was summarized in the paper. A sort of auxiliary bearing scheme was proposed. MSC.Marc was selected to analyze the vibration mode and the natural frequency of the rotor. The scheme design of auxiliary bearing and analysis result of rotor dynamics offer the important theoretical base for the protector design and control system of electromagnetic bearing of the blower fan.

Keywords: HTR-10, Electromagnetic Bearing, Auxiliary Bearing, Finite Element Method, Rotor Dynamics

1. INTRODUCTION

The 10MW high-temperature gas-cooled test reactor (HTR-10) is the first module high-temperature gas-cooled test reactor in the world. It was constructed by INET at Tsinghua University of China. The modular High Temperature gas-cooled Reactor (HTR) combined with direct gas-turbine cycle (closed Brayton cycle) can bring high inherent safety together with high efficiency[1]. So the HTRs are considered one of the most potential candidate for the new generation reactors in the 21st century, and several prototype plants are conceptually designed around the world[2-4], such as the PBMR (South Africa), the GT-MHR (Russia, USA, etc.) and the GTHTR300 (Japan) [5]. The blower fan with helium is one of the important equipments for HTR-10.

The rotor of the blower fan is being supported by the ordinary mechanical bearings. Ordinary bearings have shortcomings such as wear, oil leaks, maintenance or frequent replacement. Electromagnetic bearings are replacing ordinary bearings as the perfect sustaining assembly 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. So the electromagnetic bearings instead of the ordinary bearings will be applied to the system of blower fan.

The need to avoid contamination of the primary system, along with other perceived advantages, has led to the selection of electromagnetic bearings in most ongoing commercial-scale gas cooled reactor designs. However, one implication of magnetic bearings is the requirement to provide backup support to mitigate the effects of failures or overload conditions. The auxiliary bearing is used to support the rotor when the magnetic bearing fails to work. Especially when the rotor is rotating with high speed, the magnetic bearing suddenly doesn't support the rotor for the power off. So it is very important for the auxiliary bearing to protect the rotor system.

The weight of the blower fan rotor is about 240 kg and the rotating speed is 5400 r/min. It is a large, vertical, high-speed rotor, and the rotor's length is about 1.5 m,. This is a challenging project in theory and practice. The research status of the auxiliary bearing was summarized in the paper. A sort of auxiliary bearing scheme was proposed. MSC.Marc was selected to analyze the vibration mode and the natural frequency of the rotor. The scheme design of auxiliary bearing and analysis result of rotor dynamics offer the important theoretical base for the protector design and control system of electromagnetic bearing of the blower fan.

2. SURVEY OF AUXILIARY BEARING

The magnetic bearing system needs a back-up rotor support system (auxiliary bearing) in case the electromagnetic bearing fails or the machine does not operate. The auxiliary bearing located at the outer-bound of the magnetic bearing 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 magnetic bearing. The clearance of the auxiliary bearing is smaller than that of the magnetic bearing to protect it. Typically, fifty percent of the magnetic bearing clearance is used for the auxiliary bearing clearance[6,7].

The diversity in both requirements and applications has led to the development of several auxiliary bearing concepts, each having its own advantages and disadvantages. In general, the auxiliary bearing concepts in use today fall into six general categories. These are plain bearings, rolling element bearings, planetary bearings, zero-clearance auxiliary bearings, ceramic bearing and gas bearing. Each of the auxiliary bearing designs has its own set of advantages and disadvantages. These are summarized in Table 1.

Table 1. Advantages and Disadvantages of Auxiliary Bearing Concepts

Technology	Advantages	Disadvantages
Plain Auxiliary Bearing	1) Low-cost 2) Passive, no moving parts in bearing 3) Reduced potential for deterioration in standby mode 4) Condition, wear may be assessed by measuring clearance with EMB's	1) Higher friction coefficients, heat generation during rundown
Rolling Element Auxiliary Bearing	1) Low-cost 2) Low friction coefficients, heat generation during rundown 3) Potentially minimum volume with combined radial/thrust bearing	1) Potential for bearing/cage damage during acceleration 2) Potential for deterioration in standby mode; contamination must be avoided 3) Windage induced rotation must be prevented in standby mode
Planetary Auxiliary Bearing	1) Reduced DN for given rotor diameter and speed 2) Low friction coefficients, heat generation during rundown	1) Greater complexity and cost 2) Contamination must be avoided 3) Windage induced rotation must be prevented in standby mode 4) Potential for acceleration damage (reduced relative to rolling element bearings)
Zero Clearance Auxiliary Bearing	1) Eliminates rotor-bearing gap during rundown 2) Extended run time capability 3) Reduced DN for given rotor diameter and speed 4) Low friction coefficients, heat generation during rundown	1) Greatest complexity and cost 2) Actuation failures should be considered 3) Contamination must be avoided 4) Windage induced rotation must be prevented in standby mode 5) Potential for acceleration damage (reduced relative to rolling element bearings)
Ceramic Auxiliary Bearing	1) Endures high temperature and wear, not to be eroded, high hardness, low density and the coef	1) Lower life than steel bearing's in low speed and heavy load 2) Complicated technics, much difficulties, and high cost

	2) Well performance of self-lubricated	3) Unstable performance and bad tenacity for porosity and not uniformity of ceramic 4) Theory of ceramic bearing is imperfect
Gas Auxiliary Bearing	1) Gas as lubricant, low expense 2) Low friction very much and noise and libration 3) Works at higher and lower temperature, high rotary precision, long life	1) Bears low weight 2) Speed is limited by unstable whirling motion 3) Bad work condition 4) Frictional force possible may be large for impurity in gas, bad reliability 5) High processing precision and cost

The use of rolling element bearing for 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. DESIGN OF AUXILIARY BEARINGS

Auxiliary bearings are a part of electromagnetic bearing and intended to support the rotor in the following cases: 1) Scheduled the system of blower fan shutdown when electromagnetic bearing are de-energized; 2) Failure of electromagnetic bearing during the system operation to ensure rotor rundown till shutdown; 3) Dynamic loads exceeding electromagnetic bearing load-carrying capacity.

The scheme design has been finished. Figure 1 gives the rotor structure of blower fan. The angle contact ceramic ball bearings were selected as the auxiliary bearings. A couple of bearings were arranged by face to face. The material of the ball is ceramic.

The basic parameter is as follow:

1) Radial gaps in the central rotor position
   a) between magnetic circuits of stator and rotor of radial magnetic bearing: 0.6mm;
   b) between radial auxiliary bearing and rotor: 0.18mm.

2) Axial gaps in the central position of the thrust disk of axial EMB
   a) between thrust disk and stator magnetic circuits of axial magnetic bearing: 0.8 mm;
   b) between axial auxiliary bearing and rotor: 0.3 mm.

3) Rotation speed of the rotor: 5400 r/min.

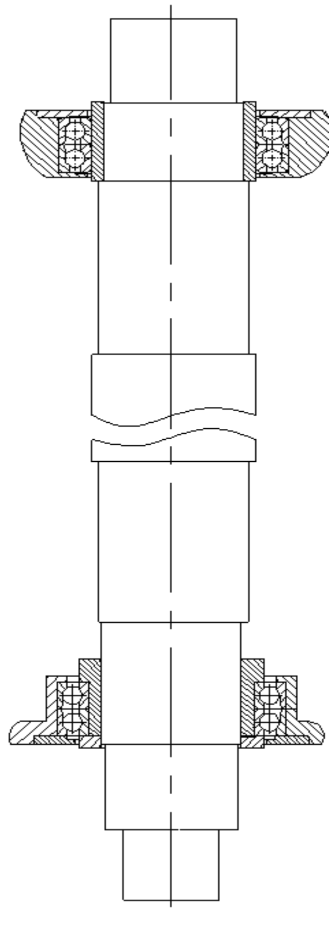


FIG. 1 THE ROTOR STRUCTURE OF BLOWER FAN

4. ROTOR DYNAMICS

Many calculating methods have been presented during the development of rotor dynamics. They are relative to previous calculating propositions and implementation. The modern calculating methods are divided into two kinds: the transfer matrix method (TMM) and the finite element method (FEM).

TMM has many useful characteristics. The order of matrixes does not increase with the increased freedom of the system. Using TMM, it is easier to write programs, less EMS memory is necessary, and calculations are performed more quickly. But the finite element model, which takes all kinds of factors into account, is a more precise model. The calculations are more accurate for complicated systems made up of a rotor and its surrounding structure. FEM did not have the instability of numerical value which occurred often in TMM.

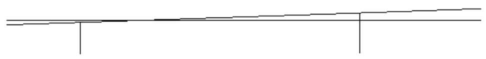
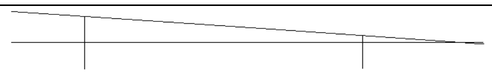
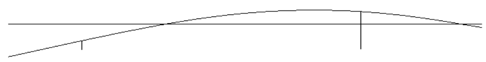
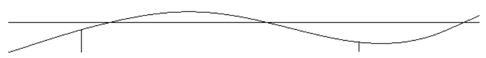
The FEM and MSC.Marc software is applied to analyze the rotor modal of blower fan in this paper. MSC.Marc is nonlinear FEM software. It has perfect solving precision.

The basic parameter is as follow:

a) material's density: 7800 kg/m^3
b) young's modulus: 2×10^{11} Pa
c) poisson ratio: 0.3
d) supporting stiffness: 1×10^{6} N/m
e) girder unit

The analytical result is listed in Table 2.

Table 2 Modal analysis by MSC.Marc

Marc(1×10^6N/m)		vibration mode	frequency（Hz）
The rotor of blower fan	1st order		3.7
	2nd order		16
	3rd order		160
	4th order		436

The first bending frequency is 160Hz (9600r/min) from Table 2. It is far from 5400r/min. So the rotor of blower fan is a rigid rotor. Figure 2 gives the relationship between the rotor speed and natural frequency. The results offer the basis for the control design of electromagnetic bearings.

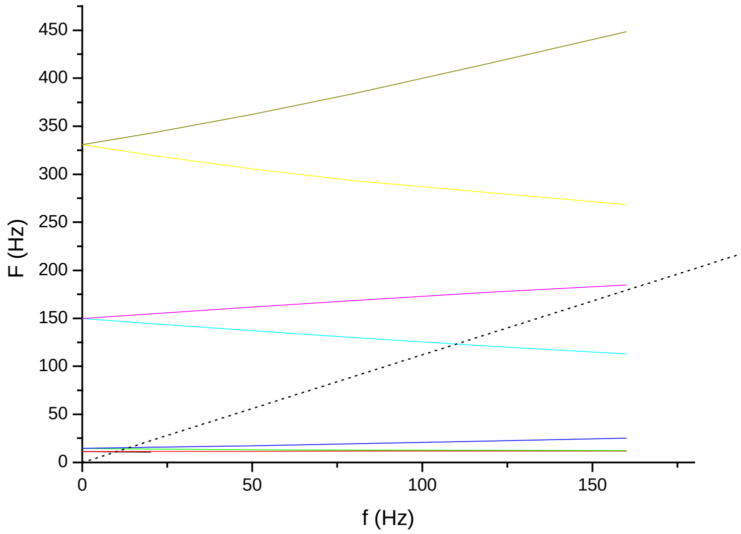


FIG 2 THE CURVE BETWEEN THE ROTOR SPEED AND NATURAL FREQUENCY

5. CONCLUSIONS

The blower fan is one of the important equipments. The ordinary bearings are being used to support the rotor of the blower fan. The electromagnetic bearings instead of ordinary bearings will be applied to support this rotor. The auxiliary bearings are important backup supporting system for the rotor when the electromagnetic bearings fail to work. The structure of auxiliary bearings is designed, and the modal analysis of the rotor is finished in this paper. These results offer important base for designing the electromagnetic bearings.

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