Preliminary Structural Design and Dynamical Analysis of Auxiliary Bearing for HTR-10GT *

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***Abstract* –The electromagnetic bearing was chosen to support the rotor of power conversion unit (PCU) and helium blower fan in 10MW high temperature gas-cooled reactor (HTR-10GT), and the auxiliary bearing was applied in the HTR-10GT as the backup protector. HTR-10GT is the second phase of the 10MW high-temperature gas-cooled test reactor (HTR-10). 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. A direct gas cycle to replace the current steam cycle of HTR-10 was studied in the HTR-10GT. 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 PCU rotor's length is about 7 m, its weight is about 1500 kg and the rotating speed is 15000 r/min. The rotor's length of helium blower fan is about 1.5 m, its weight is about 240 kg and the rotating speed is about 5400 r/min. The design of the auxiliary bearing is one of the challenging problems in the whole system. It is very important for HTR-10GT to make success. In this paper, the research status of the auxiliary bearing was summarized. A sort of preliminary scheme of auxiliary bearing structure was proposed. The falling course was analyzed. The stress of the rotor and auxiliary bearing was computed by the finite element method. MSC.Marc was selected to analyze the vibration mode and the natural frequency of the rotor. The scheme of auxiliary bearing and the analytical results offer the important theoretical base for the protector design of the HTR-10GT.**

***Index Terms* – Active Magnetic Bearing, Auxiliary Bearing, High Temperature Reactor (HTR), Finite Element Method**

I. INTRODUCTION

The 10MW high-temperature gas-cooled test reactor (HTR-10) is the first module high-temperature gas-cooled test reactor in the world. HTR-10 was designed and constructed by the Institute of Nuclear Energy Technology (INET) of Tsinghua University. The steam cycle has been applied in the power conversion unit (PCU) of the HTR-10. This technology is mature and reliable. In order to sufficiently use the quantity of heat produced by the high-temperature reactor, a direct gas cycle to replace the current steam cycle was studied in the HTR-10 phase II (HTR-10GT). Helium was chosen as the medium to achieve a direct helium cycle[1].

If oil bearings are used as the supporting assembly in the PCU for the direct helium cycle, oil leaks from the bearings would be likely to occur. Ordinary bearings are not adaptable for shortcomings such as wear, maintenance or frequent replacement. Electromagnetic bearings are replacing ordinary bearings as the perfect sustaining assembly for the PCU 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[2].

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 research status of the auxiliary bearing was summarized in the paper. A sort of preliminary scheme of auxiliary bearing structure was proposed. The rotor stress and modal analysis was computed by the finite element method with MSC.Dytran and MSC.Marc. The scheme of auxiliary bearing and the analytical results will be used in the HTR-10GT.

II. 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 an "auxiliary bearing" or a back-up bearing. Being assembled on the stator, the auxiliary bearing is not active during the normal

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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[3, 4].

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.

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.

III. Analysis of Falling Course for PCU Rotor

Auxiliary bearings are a part of electromagnetic bearing and intended to support the HTR-10GT rotor in the following cases: 1) Scheduled HTR-10GT shutdown when electromagnetic bearing are de-energized; 2) Failure of electromagnetic bearing during HTR-10GT operation to ensure rotor rundown till shutdown; 3) Dynamic loads exceeding electromagnetic bearing load-carrying capacity.

The preliminary scheme design has been finished by INET and OKBM, Russia. Figure 1 gives the preliminary structure of HTR-10GT rotor. The generator is fixed on the top of the rotor, and the turbine machine is fixed on the bottom of the rotor. The position of the radial magnetic bearing lies in areas 2, 3, 8 and 9 shown in Figure 1. The position of the axial magnetic bearing lies in areas 4 and 7 shown in Figure 1. The position of the radial auxiliary bearing lies in areas 1 and 10 shown in Figure 1. The position of the radial-axial magnetic bearing lies in areas 5 and 6 shown in Figure 1.

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: 0.7mm;
   b) between radial auxiliary bearing and rotor: 0.15mm.
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: 1.0 mm;
   b) between axial auxiliary bearing and rotor: 0.3 mm.
3) Rotation speed of the TM rotor
   a) nominal: 250 s^{-1} (15000 r/min);
   b) maximal: 300 s^{-1} (18000 r/min).

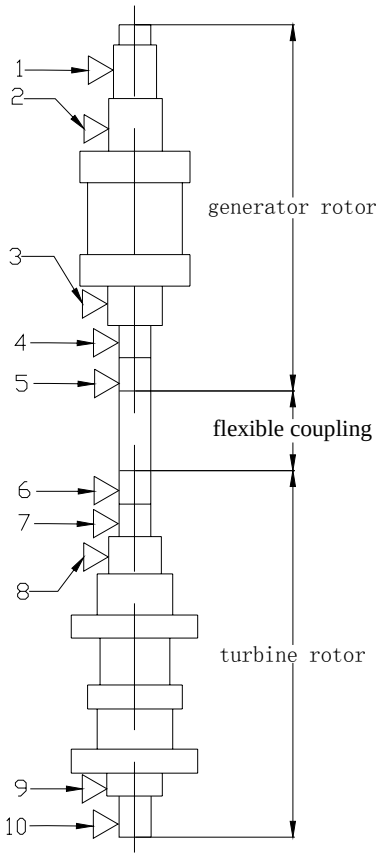


Fig. 1 The structure of HTR-10GT rotor

The touchdown process is usually divided into four distinct regimes of motion: free-fall, impact, sliding-whirling, and rolling[5].

It is difficult to analyze the falling course of the rotor. The preliminary analysis of generator rotor was done in the special condition by the finite element method and MSC.Dytran software.

The finite element model of the generator rotor is showed in figure 2. The rotor falls into the auxiliary bearing at the speed of 15000r/min when the magnetic bearing fails to support the rotor.

When the rotor falls without excursion, the coefficient of friction is supposed to 0.1. The stress of the generator rotor is 1160MPa. The stress of the radial-axial auxiliary bearing is 945MPa. The stress of the radial auxiliary bearing is 0.

When the rotor falls with the excursion, the coefficient of friction is supposed to 0.05. The angle of the excursion is 0.030. The stress of the generator rotor is 1800MPa. The stress of the radial-axial auxiliary bearing is 2000MPa. The stress of the radial auxiliary bearing is 1200MPa. If the coefficient of friction is 0.1, the maximal stress of the rotor or auxiliary bearing exceeds 2000MPa. So the excursion will bring serious result. The preliminary result will offer the important reference for the design of auxiliary bearing.

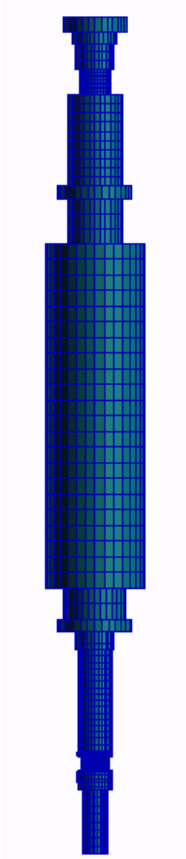


Fig. 2 The finite element model of the generator rotor

IV. Design and Analysis of Auxiliary Bearings for Helium Blower Fan

The scheme design has been finished. Figure 3 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.

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/m3
b) young's modulus: 2×1011 Pa
c) poisson ratio: 0.3
d) supporting stiffness: 1×106 N/m
e) girder unit

The analytical result is listed in Table 1.

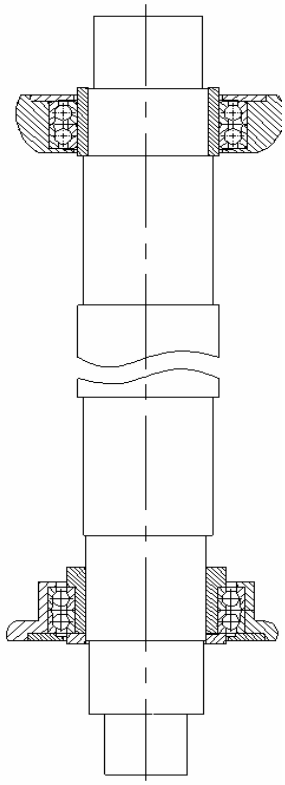
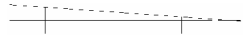


Fig. 3 The rotor structure and helium blower fan

TABLE I.
MODAL ANALYSIS OF HELIUM BLOWER FAN

	vibration mode	frequency（Hz）
1st order		3.7
2nd order		16
3rd order		160
4th order		436

The first bending frequency is 160Hz (9600r/min) from Table 1. It is far from 5400r/min. So the rotor of blower fan is a rigid rotor. Figure 4 gives the relationship between the rotor speed and natural frequency. The results offer the basis for the control design of electromagnetic bearings.

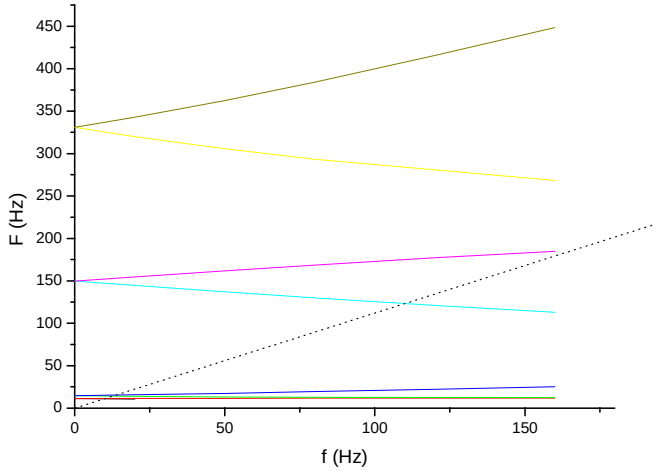


Fig. 4 The curve between the rotor speed and natural frequency

V. CONCLUSIONS

HTR-10GT is the first pebble-bed high temperature gas-cooled test reactor together with direct gas turbine designed and built by the INET in China. The research status of the auxiliary bearing was summarized in the paper. The preliminary scheme of auxiliary bearing structure was proposed. The falling course was analyzed, and the stress of the generator rotor and modal analysis of helium blower fan was computed. The analytical results offer the important theoretical base for the auxiliary bearing design of HTR-10GT.

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REFERENCES

[1] Guojun Yang, etc. Preliminary Modal Analysis and Structure Design of AN HTR-10 PCU Rotor with An Active Magnetic Bearing. 11th International Conference on Nuclear Engineering. Tokyo, Japan. 2003,4.

[2] Gerhard Schweitzer, etc. 1994, Active Magnetic Bearings, Vdf Hochschulverlag AG an der Eth Zürich.

[3] T. Ishii, R. Gordon Kirk. Transient Response Technique Applied to Active Magnetic Bearing Machinery During Rotor Drop. Trans. of the ASME. 1996.4, 118: 154-163

[4] X. Wang, S. Noah. Nonlinear Dynamics of a Magnetically Supported Rotor on Safety Auxiliary Bearings. Trans. of the ASME. 1998.4, 120: 596-606

[5] Jinchen Ji, Lie Yu. Drop Dynamics of a High-Speed Unbalanced Rotor in Active Magnetic Bearing Machinery. Mech. Struct &