Finite element analysis and experimental studies on hybird magnetic bearing

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Abstract*—Energy storage technology is still a restriction to limit the commercialization of HEV since its high cost, short mileage and long charge time. Flywheel energy storage system(FESS) is a new way to storage energy in HEV, which can solve those problems mentioned above. Magnetic bearing is the key point of FESS. To research the characteristic of axial-active, radial-passive hybrid magnetic bearing, finite element analysis method is introduced to set up the model of axial and radial structure. Forces of different displacement and the possibility of rotor floating are analyzed, and one kind of operating point is obtained. In the final analysis, the whole magnetic bearing is developed, and experiment system is built to get the relations between axial electromagnetism force and axial displacement, and also to get floating current at different axial displacement from experiment. It can be concluded that the results of experiment and simulation are in good agreement. With the comparison between the results of experiment and finite element analysis method, correctness and validity of the finite element analysis method are verified. It provides a calculation method and theoretical reference for the further research of magnetic bearing.

Keywords-HEV; flywheel energy storage system; hybrid magnetic bearing; axial and radial structure; finite element analysis; mechnical characteristics; operating point;

I. INTRODUCTION

Magnetic bearing is a new type of magnetic machinery, it makes the good use of magnetic rotor suspended in the space to be a new high-performance bearing[1]. As between the rotor and stator without any mechanical contact, there is no mechanical friction, with low loss, low noise, low vibration, no lubrication, environmental pollution was small, and ultra-high speed operation and other characteristics of long-term.

According to the magnetic field strength magnetic bearing can artificially control, the magnetic bearings are divided into three types: active magnetic bearing, passive magnetic bearing and hybrid magnetic bearing. This paper introduces the ansoft finite element software to analysis an active axial control and radial passive control of the hybrid magnetic bearing. It also analysis relations between axial suction force of axial magnetic bearing and axial displacement, and the possibility of floating the rotor. For the radial magnetic bearing radial stiffness of the relationship with the axial displacement, it is analyzed, and the way of the working point setting up makes some valuable conclusions.

Finally, a magnetic bearing is realized, and an experimental platform of magnetic bearing is built. Through the experimental analysis, the relationship of axial magnetic bearing force and axial displacement, a different axial position at floating current size is obtained, and compared with the simulation results to verify the finite element model is correct and rationality. Further study of the performance of hybrid magnetic bearing provides some reference and theoretical calculation methods.

II. THE STRUCTRURE AND SIZE OF THE HYBIRD MAGNETIC BEARING

A. the advantages of the hybird magnetic bearing

This kind of structure of hybrid magnetic bearing, its axial structure is made by two suction disks and an iron plate. Suction disc is with coil windings. Current in suction disk windings can adjust instantly so as to control the axial freedom of the iron plate actively. The structure of hybrid magnetic bearing is shown in Figure 1.

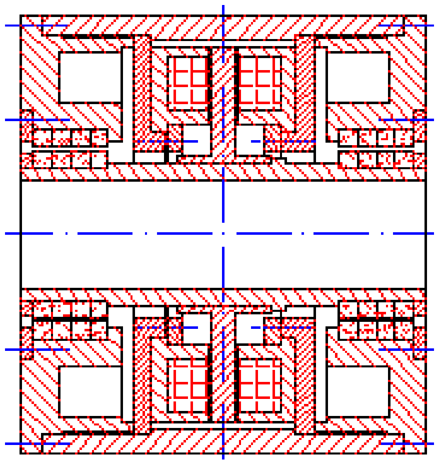

Figure 1. Strcture of hybird magnetic bearing

This structure combines the advantages of active magnetic bearings and passive magnetic bearings, not only to simplify the active control of the magnetic bearing, but also to satisfy the conditions for suspension.

B. Parameters of the hybird magnetic bearing

Radial structure of magnetic bearing is realized with annular permanent magnets and it can keep balance of the bearing automatically. Such a structure can run without active control, totally dependent on the radial permanent magnet repulsion to control the remaining four degrees of freedom of the rotor except the degree of freedom of axial rotation, making radial magnetic bearing rotor balancing. Radial size of the structure is as follows:

Inner diameter of inner loop is 42mm，outer diameter of inner loop is 54mm, inner diameter of outer loop is 55.6mm, outer diameter of outer loop is 67.6mm, mean radius is R_m =27.4mm, Radial thickness is equal to the axial thickness, and the value is: h=L=6mm, gap is: g=0.8mm.

TABLE I. PARAMETERS OF HYBIRD MAGNETIC BEARING

Outside diameter of shaft	**Outside diameter of magnetic bearing**	**Inside diameter of suction disk**	**Outside diameter of suction disk**	**Inside diameter of windings cavity**	**Inside diameter of windings cavity**
35mm	140mm	70mm	120mm	80.2mm	113.4mm

Height of windings cavity	**Width of windings cavity**	**Magnetic flux density at work place**	**Area of gap and core magnetic circuit**	**Length of gap magnetic circuit**
16.6mm	13.5mm	0.4019T	1200 mm^2	0.5mm

III. FINITE ELEMENT ANALYSIS OF DIFFERENT STRUCTURES

A. Axial magnetic bearing strcture of finite element analysis

In the finite element software, axial suction disk model is created, as shown in Figure 2.

The iron disc rotor and the suction plate parts of the model are all used with #45 steel, conductive coils inside the suction plate use copper material. Normal working current is set with 320A. Normal working air gap is 0.5mm, and up and down each with 0.5mm gap. In the normal scope of work, the model is valid.

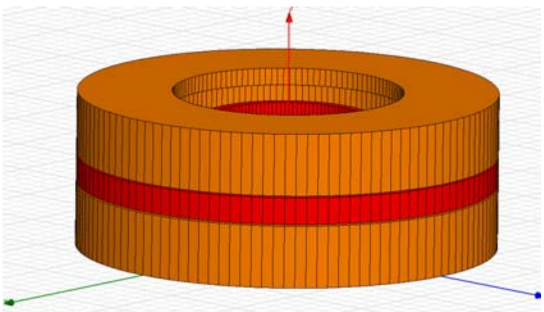

Figure 2. Axial suction disk, three-dimensional finite element model

Finite element analysis of the force of axial suction disk is done under the normal work of the 320A rated current conditions.

Figure 3 is the distribution of magnetic field lines, which is under the condition of the distance between the suction plates is 0mm.

The figure clearly shows that the magnetic field lines are basically into a uniform distribution, when the radial distance does not move.

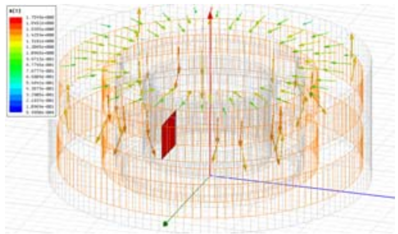

Figure 3. Axial distance 0mm when the three-dimensional magnetic field lines distribution

In the following paper, the electromagnetic force changes are discussed with the role of unilateral currents affected, as shown in Figure 4. From the chart analysis, it can be known that the force of suction disk on the iron plate with the axial displacement is not a linear change line, from 0mm to 0.5mm, the axial force changes dramatically, especially the distance between iron plate and suction plate is zero, the force is 1381.7N, while the distance between 0.5mm to 1.0mm, the change of axial force is not apparently, and the values are below 30N. As the suction plate axial force generated is non-linear, and with the distance between the two decreases, the axial force will be a sharp increase. Both sides are with current, when an iron plate from the side close to the other side provided by the electromagnetic force will be unable to make an iron plate back to the center's work location of department, this situation may cause the magnetic bearing failure. So it is necessary to improve the structure of magnetic bearings.

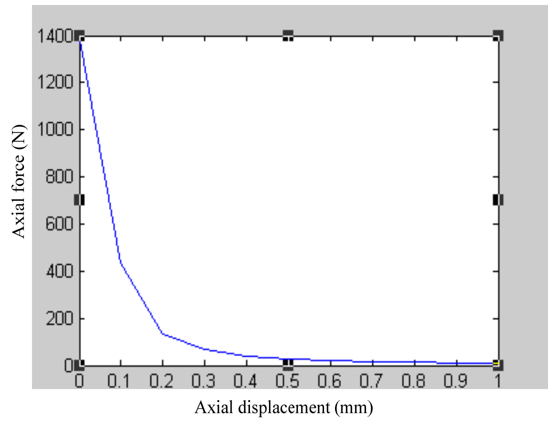

Figure 4. Axial force - axial displacement curve of 320A current

Based on the analysis of this likely scenario, it proposes some measure to improve this structure in this paper. This measure is to add the axial support bearings at both ends of the stator. Such auxiliary bearings and the rotor axial distance preferable are designed to be half of the normal working gap. The mid-point at working air gap of the magnetic bearings studied in this paper is 0.5mm, therefore desirable auxiliary bearing and the outer end of the rotor axial clearance can be designed to 0.25mm. The introduction of auxiliary stator and rotor bearings can be avoided the case that too large to be offset from the rotor back, making magnetic bearing always been able to work in the effective area.

IV. RADIAL MAGNETIC FINITE ELEMENT ANALYSIS OF RING

A. Finite element analysis model and cauculation of radial magnetic ring

The carrying capacity of magnetic bearings is mainly decided by the axial magnetic force generated by the suction plate. However, in this hybrid-type magnetic bearing system, due to the presence of permanent magnet rings, it needs to consider the effect that the forces of magnetic ring act in the axial direction. The forces of magnetic ring act in the axial and radial direction carried out a systematic analysis to arrive at this type of permanent magnetic bearings operating point. It provides for different situations of modular operating point setting method, which reflects an extremely important application value in engineering.

According to the structure of permanent magnetic rings, this paper choices model 38SH of NdFeB material for the study. Established finite element model is shown in Figure 5.

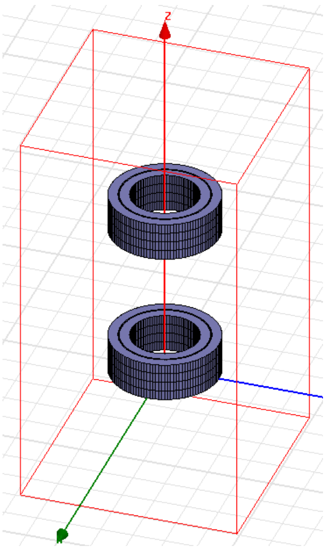

Figure 5. Three-dimensional finite element model of permanent magnetic ring

B. Radial magnetic ring finite element calculation results and analysis

The work carried out for different finite element simulation calculations, a set of data and calculation results are fitted as shown in Figure

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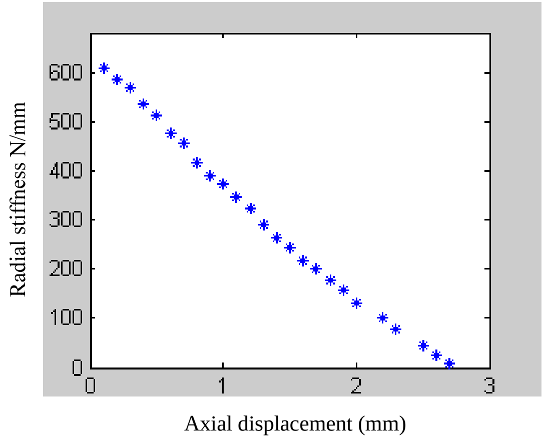

Figure 6. Axial displacement- radial stiffness curve

B_r=1.24T, H_c=907kA/m of this material. Figure 6 fitted the axial position near the axial center, radial stiffness-axial displacement curve. From 0mm to 2.7mm, radial stiffness gradually decreased from the peak to zero. After 2.7mm, the radial stiffness change direction, from repulsion to attraction by the permanent magnet ring. Radial stiffness in the 2.7mm rather than 3.0mm at a single magnetic ring center reduced to zero. Therefore, the location of critical point is in front of the center of the location of 3mm.

C. Axial operating point setting method of radial magnetic ring

In practice, productions are inevitably with deviations of accuracy during the machining processing, which can result that permanent magnetic ring after the installation can not be completely symmetrical. Deviation of this process of magnetic bearing on the work of the impact can not be ignored. In addition, as the system in this paper requires using an iron plate axis and the suction plate to achieve the control of axial force, axial force can be provided is relatively limited.

For example, the magnetic ring in the center of the work conditions, if it carries 50kg of weight, will produce 500N axial force, if at the same time there is deviation down in the axial direction, such as the downward offset 0.1mm, then the resulting magnetic ring along the axial downward force is 131N, add with gravity would result in downward force of 631N. An iron plate can not produce an effective suction to suck back to the position of equilibrium rotor under this air gap, so the magnetic bearing will also in consequence be invalidated. Therefore, in the center, although the magnetic ring radial stiffness can reach the maximum, however, may make the impact of axial magnetic bearing not work correctly.

Therefore, the working point setting of the permanent magnet ring is particularly important. Without affecting the radial stiffness, if we make the permanent magnet ring biased some distance, that is, on the permanent magnet ring in the axial offset a certain distance, as shown in Figure 7.

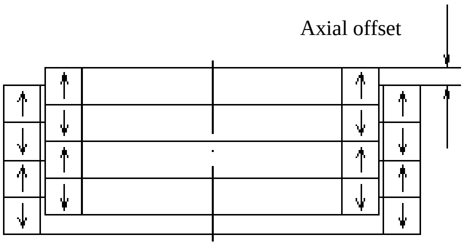

Figure 7. Work of bias magnetic ring

In this way, inner permanent magnets will be subject to upward force, and using the force of permanent magnetic ring biased to offset gravity generated by the load, setting a new operating point, in order to make the gravity of load just be equal to the axial force generated by the magnetic bearing. at this point, axial plate in the case of small displacement, only need to provide a smaller current, force generated by the windings will be able to make a balance. In this way, advantage of this magnetic bearing with its own unique structure is absolutely used. For this structure of the magnetic bearings, the study of the working point setting has great theoretical significance and important practical application value.

Figure 8 is based on simulation results, the given axial load in different cases, permanent-magnet ring operating point setting curves.

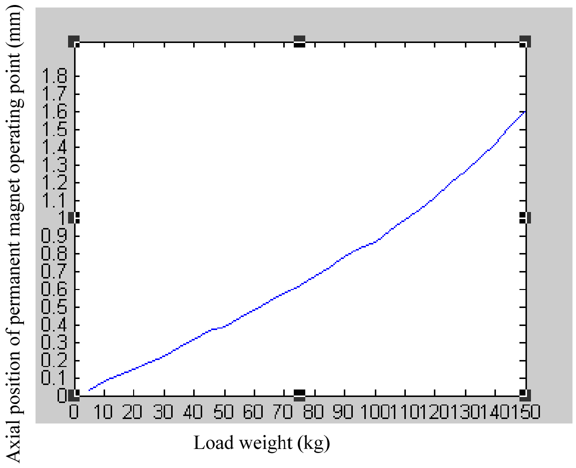

Figure 8. Permanent magnet ring operating point setting reference curve

V. Hybrid Experimental Study of Magnetic Bearing

A. *Magnetic bearing assembling and experiment platform building*

After the simulation and calculation, a model of hybrid magnetic bearing is realized, which is shown in Figure 9, and some tests based on the model is set up to verify the research results as is shown in Figure 10. The results will be presented in the subsequent paper.

Figure 9. Prototype of magnetic bearing

Figure 10. Platform for experiment

B. *Testing of axial force*

Experiment system is built to get the relations between axial electromagnetism force and axial displacement, and also to get floating current at different axial displacement from experiment. Fitted curves are shown as below.

Curve of axial force-axial displacement tested in experiment compared with the curve getting from simulation. The blue line is experiment curve, and the red one is simulation curve. As shown in Figure 11.

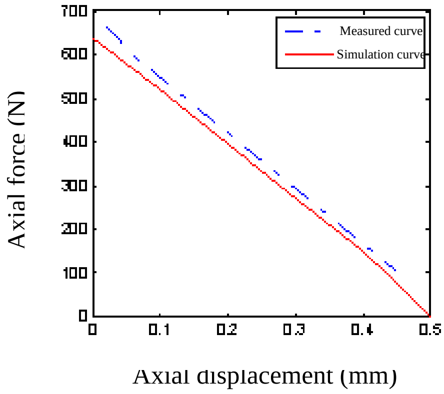

Figure 11. Curve of axial force-axial displacement tested in experiment compared with the curve getting from simulation

Figure 11 can be seen that the actual obtained measured curve and the simulation curve of the relationship between axial force and displacement are in good agreement.

The experiment also measures the relationships between float current and the rotor axial position. The basic principle of measuring is that the axial displacement adjustment device for the use of gradually adjust the actual location of the rotor, respectively, for each different location, measures a minimum current value to enable a suction disc rotor floating. Take the actual measured curve and the curve of finite element for comparison, as shown in Figure 12. The blue line is experiment curve, and the red one is simulation curve.

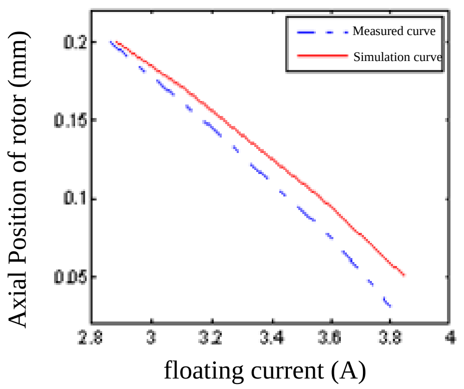

Figure 12. Comparation between test and simulation of relations of axial displacement and floating current

The experiment also gets a set of unilateral coil relationships of current and the rotor axial displacement with the same measured electromagnetic force. The fitted curve is shown in Figure 13.

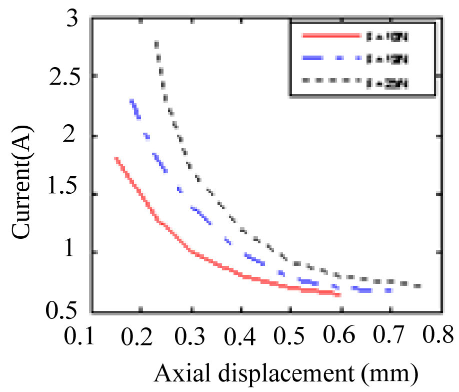

Figure 13. Rlations between one unilateral of current and displacement with the same electromagnetism force

VI. Conclusion

1) A radial permanent magnetic ring and axial suction plate finite element analysis model is established to analyze axial and radial forces with the changing of axial and radial displacement. The different working conditions for the analysis of the curves under different circumstances to the magnetic bearing shaft of the work force as well as the magnetic ring provides the possibility choice of analyzing the different working conditions.

2) It is very easy to obtain the optimal operating point setting position according to different load by looking on the working set curve. For different actual situation, to find the best conditions for each design, the magnetic bearing of the operating point can be optimized settings. This conclusion is very important in the practical application.

3) The prototype experimental research to verify the feasibility of the design. The relationship between axial force and axial displacement is obtained, as well as the float current of different axial location, and finite element simulation of the results obtained are compared, the two conclusions are basically consistent to verify the correctness of finite element analysis.

References

[1] Han Zhao, Zhiyi Yang, Zhongchen Wang. “Comparison of two kinds of magnetic bearings calculation model,” Tansactions of the Chinese Society for Agricultural Machinery 2002, 33(4):84-85