GEOMETRICAL DESIGN FOR A LARGE MAGNETIC SUPPORTING SYSTEM CONSIDERING COUPLING EFFECT

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ABSTRCT
Large magnetic supporting system is a typical magnetic machine, and it would bring greater errors by conventional method to design its structural and electromagnetic parameters. This paper uses coupled field-circuit design method, against the present design methods' defects, to provide interaction design method of structural and electromagnetic parameters by the electromagnetic parameters, structural strength and stiffness design and analysis on supporting system components, and verify the feasibility of such design method.

INTRODUCTION

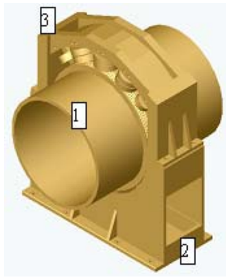
Magnetic mechanism use magnetic energy to produce power, drive and control executive components without contacting. It is one of the main directions among a variety of applications to achieve supporting function by electromagnetic force, and has been used widely abroad. In China related researchers have devoted much attention in this direction, such as magnetic bearings and magnetic suspension train, etc, but the design method still needs continuous improvement.

Method of magnetic-circuit is used widely in the area of engineering application, however, has defects in low accuracy and cumbersome design; Analysis of magnetic field can give more accurate distribution of field, but needs definitively analytic models, complex calculation and mass work. If the two is combined, it can effectively improve the accuracy and efficiency of magnetic mechanism design with the geometric models designed beforehand by the method of magnetic-circuit and parameters tested and adjusted by analyzing field. On the other hand, the principal characteristics of magnetic mechanism require that the process of analysis and design must reflect the possibly existent coupling effects between two fields. So it is the basis of magnetic mechanism theory and applications research to improve the defects in traditional design such as cumbersome design, high errors and so on. This paper uses the way of interaction of structural and electromagnetic parameters to design the structure of a large-scale magnetic suspension system by the design idea of coupled field-circuit and considering coupling, and verifies the feasibility of the design method.

CONTENTS AND METHODS OF DESIGN

The large-scaled spindle is 9.94m long whose supporting part made of 08F steel is 6.8 tons weight with section outer diameter 706mm and inside diameter 664mm. The spindle is joined of several rollers of the same structure. As a result of the oversized radial direction, there are four supporting:

(a) The Middle Rigidity Idler



(b) The Planning Electromagnetism System

FIGURE 1 : The Previous Bearing and It's Substitute Structure of Some Great Principal Axis

The both sides are supported by bearing while the middle is supported by two rigid idlers. The rigid roller supports the structure and do pure running when the spindle rolls. The bearing structure of the rigid roller is showed in picture 1(a). When it rotations by 300 revolutions a minute or higher, as a result of high revolving speed, Final Structure producing heat, intense vibration and noise. The system's features indicate that the middle rigid roller as the main bearing structure limits the spindle speed. In order to improve the spindle's operating performance, this paper remain the both sides bearing supporting and the driving form and replace the two rigid idlers by two non-contact magnetic supporting. In the original point, the electromagnetic system produces suction as a secondary support of the spindle. Alternative system improves vibration, shock and noise to enhance spindle speed.

The designed electromagnetic supporting system is shown in Figure 1(b), 1 is the principal axis, 2 is the original supporting base, and 3 is the electromagnetic support. The content includes electromagnetic parameter and structural mechanical strength and stiffness design based on field-circuit way. In order to express coupling, the two achieve parameters interaction during design. The specific method is shown in Figure 2.

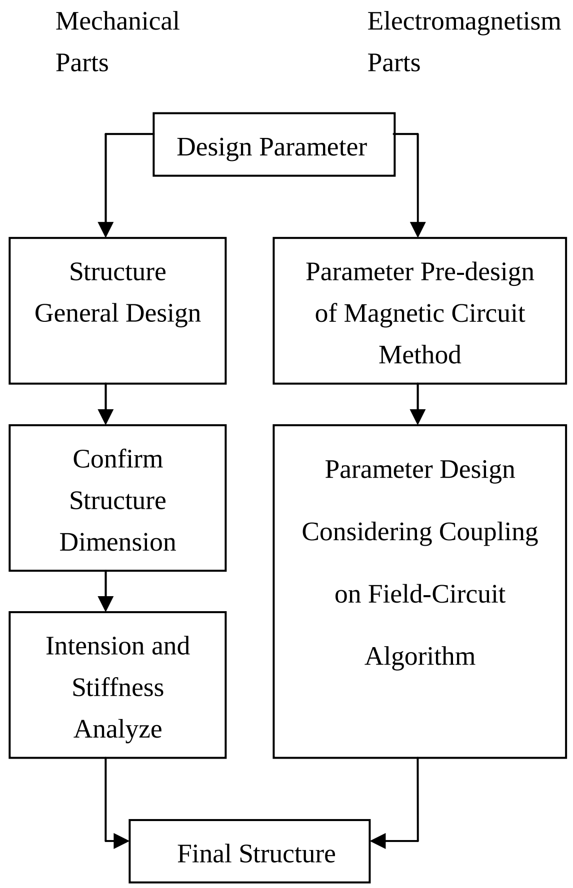


FIGURE 2: Design Method of the Electro-magnetism Bearing System

STRUCTRUE AND ELECTROMAGNETIC PARAMATER DESIGN

According to the structural design shown in Figure 1(b), 4 groups of electromagnetic coils is used as excitation source and the middle 3 coils make a line package. Use stator windings and circular structure. Such windings is a overall pattern of 4 groups of U-shaped magnets and produced of 20 steel materials which have a good selective magnet and mechanical strength, being grooved to install coil. The coil is provided with the DC electromagnetic force to keep the spindle in balanced position which makes the outer surface 2 mm from the magnetic pole. The cylinder is ±1mm beating from top to bottom (the measured value of original system's beating), so designing electromagnetic parameters is calculated by the distance from the outer surface to the pole (1-3) mm.

It is easy to design related electromagnetic structural parameters s according to needed electromagnetic force by magnetic circuit way. The calculating content includes establishing static working points, calculating the number of coil, identifying the area of magnetic pole, and other structural parameters.The structural electromagnetic parameters' calculating results are shown in Table 1.

TABLE 1 Main Structure Parameter Pre-design of the Stator and Loop

Structural parameters	Unit	Design value
Current density	A/mm^2	2
Current	A	2
Ampere turns	AN	1671
Coil area	mm^2	1671
Window area	mm^2	7225.8
Polar arc length	mm	40.1
Yoke thickness	mm	40
Polar width	mm	40
Winding width	mm	49.1
Coil height	mm	68.1
Polar height	mm	109.3
Electromagnetic suction	N	26150
Temperature rise	℃	36.5

ELECTROMAGNETIC STRUCTURAL PARAMETERS' NUMERICAL SIMULATION AND INTERACTIVE DESIGN

The model based on pre-design, using two-dimensional static circuit analysis, inspects the distribution and size of the electromagnetic force in magnetic field; by the three-dimensional structure finite element analysis of the stator support, calculate the supporter's stress and deformation; according to the results to design on structure and electromagnetic parameters to adjust the pre-design parameters. The design process is shown in Figure 3.

To analyze the two-dimensional electromagnetic (Figure 4) and three-dimensional structural field on the models of pre-design (Figure 5), and getting parameters of magnetic field distribution, electromagnetic force, structural deformation, stress and other fields.

Electromagnetic analysis shows that under the condition of 1671 the turn of every turn, stators appear magnetic saturation phenomenon (analysis ignores magnetic nonlinear); there are not all completely average fields in the gap, making marginal effect in the magnetic pole; coupling is made among poles; magnetic field gives about 10 percent MFL to the surroundings; the system has a very small force in the horizontal direction while a smaller force than it calculated by magnetic field method because of the effect of factors such as magnetic flux leakage and marginal effect, but within the field of design requirements.

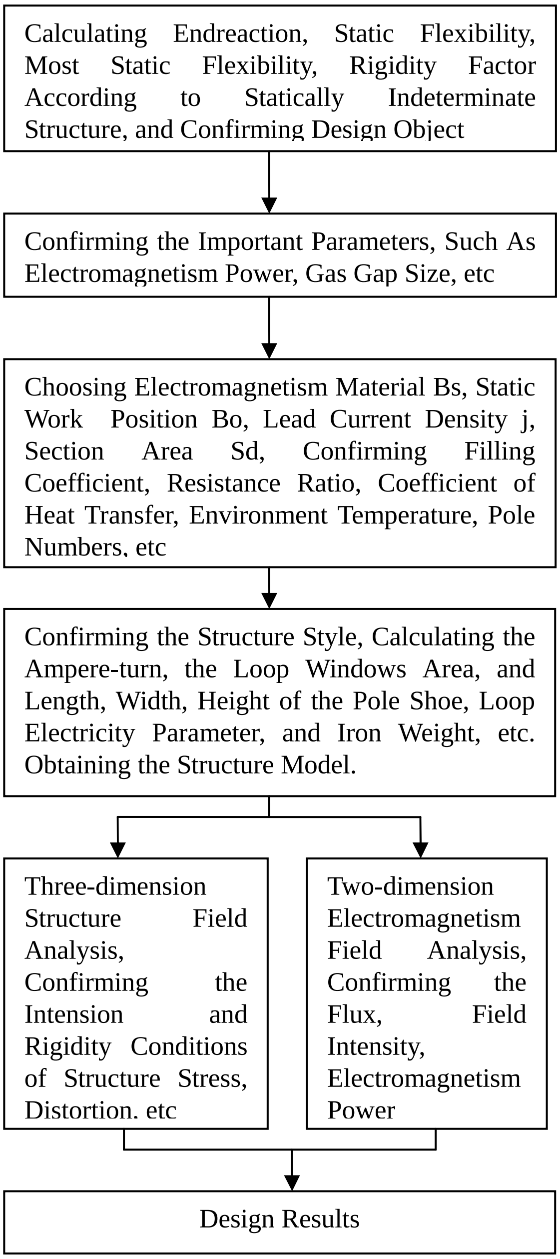


FIGURE 3: Design Flow of Electromagnetism Bearing Structure and Electromagnetism Parameter

Structural field analysis indicates that the biggest deformation appears in the longitudinal centerline cross of reinforcement plate with the value of 0.05mm; the greatest von mises stress appears in the combined hole of bracket and electromagnet with the value of 21.7Mpa, and other parts' stress and deformation are both small. As the gap between electromagnetic supporting rotor is 1-3mm, the supporter' strength and stiffness can meet the requirements.

DESIGN ANALYSIS AND RESULTS

Based on the results of field quantity analysis, considering the coupling of structure and

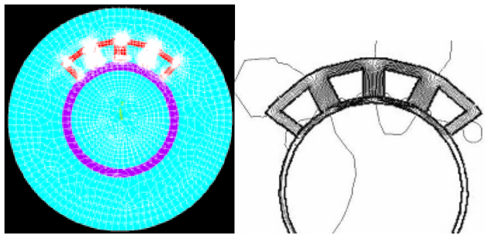


FIGURE 4: Two-dimension Electro-magnetism Field Analysis of the Bearing

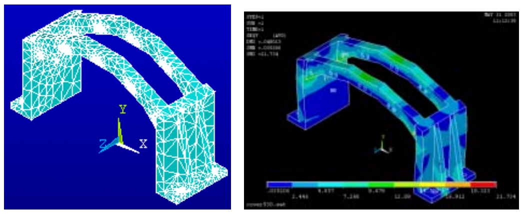


FIGURE 5 : Three-dimension Electro-magnetism Field Analysis of the Bearing

electromagnetic parameter design, modifying the original design parameters achieves the design result. The main electromagnetic and structural parameters are shown in Table 2.The final drawing relevant sizes are given fine adjustment according to making requirements.

TABLE 2 Structure and Electromagnetism Parameter Design Considering Coupling on Field-Circuit Algorithm

Structural parameters	Unit	Design value
Current density	A/mm2	2
Coil area	mm2	1671
Window area	mm2	9690
Polar arc length	mm	40
Yoke thickness	mm	40
Polar width	mm	40
Polar height	mm	123.1
Electromagnetic suction	N	24544
Temperature rise	℃	24

Compare the structural and electromagnetic parameters by coupled field-circuit considering structural and electromagnetic parameters coupling with them based on magnetic circuit method. The results are shown in Table 3.

According to the installation requirements, the parameters of pole arc radius, pole wide, excitation turns are not changed. It can be indicated in Table 3 with unchanged excitation consideration.

(1) According to structural strength and stiffness considerations without effecting electromagnetic force, decreasing thickness of both side plates and magnetic yoke width can reduce iron weight and compact structure.

TABLE 3 Contrast Between This Paper and Normal Design Method

Design parameters	Normal design method	Design method of this paper
Bilateral vertical plates' thickness(mm)	60	45
Magnetic yoke's thickness(mm)	50	40
Magnetic polar height(mm)	109.3	123.1
Coil unilateral width(mm)	49.1	46.4
Coil height(mm)	68.1	82
Iron weight(N)	840	615
Copper weight(N)	418	418
Total weight(N)	1258	1033
Temperature rising Δt (°C)	36.54	24
Absolute error between temperature rise and measured value (°C)	21.54	9
Static electromagnetic force(N)	26450	24544
Relative error between electromagnetic force and measured value(%)	13.7	6.7

(2) According to structural strength and stiffness considerations, adjusting pole height can change coil size to enlarge window area, so the calculating temperature rising error (measured temperature rising is about 15℃) decreased.

The error between the static electromagnetic considering magneto resistance and saturation effects and the measured results reduced from 13.7％ to 6.7％. The results show that on the non-static working points, electromagnetic errors by conventional design methods are bigger, and the electromagnetic force calculated by the design method of this paper conforms to reality.

With structural and electromagnetic parameters established, considering production process of all parts, design every structural drawing. Coil excitation uses regulator DC power. The completed product is shown in Figure 6.

FIGURE 6: Supported by the two electromagnetic alternative to the original appearance of rigid support of the spindle

When designing excitation current, the reverse calculating electromagnetic force by measuring deflection is consistent with the design one: getting 2.3T (left) and 2.5T (right) vertical force by adjust excitation current on installation points. The cutter machine spindle's vibration, shock and noise have been improved significantly under the normal working speed. The results indicate that the design method considering coupling field-circuit is feasible in magnetic mechanical structural and electromagnetic parameters design.

CONCLUSION

This paper provides geometrical design for components aimed at the large magnetic supporting system in the view of field-circuit integrated way and considering coupling effect, using the method of interactive design between structure and electromagnetic parameters, combining conventional design calculation and field analysis and taking account of the typical coupling effects. By the supporting system components' electromagnetic parameters design and analysis, structural strength and stiffness design and analysis, the process and result of structural and electromagnetic parameters interaction design are given. Compared with normal design method, the rotor magnetic suspension system of such design method, without impacting the electromagnetic force, reduces iron weight, compacts structure, closes the measured temperature rising and the calculating static electromagnetic force's errors decreases. The measured values verify the feasibility of the method.

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