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The Calculation of the Centripetal Force of a Magnetic Suspension System using ANSYS

Wang Xiaoguang[1,a], Fang Huijuan[1,b]
[1]School of Mechanical and Electronic Engineering, Wuhan University of Technology, Wuhan, 430070, China
[a]xgwang55@163.com, [b]cherry100424@163.com

Abstract: The centripetal force of a magnetic suspension disc is compared by experimental results, calculating by use ANSYS and calculating by Force-Balance method. Research results show that centripetal force of a magnetic suspension system is related to the structure and control system. For the control currents of the magnetic suspension disc are not known in advance, thus it is impossible to directly adopt ANSYS to calculate centripetal force, the control currents of the magnetic suspended disc measured by experiments is used to form ANSYS calculation model. The calculate results using ANSYS match well with the experimental measurements. The calculation of Force-Balance method is not applicable to calculate centripetal force of the magnetic suspension system. The process of the calculation is introduced and the error in the calculation is analyzed as well.

Keywords: Magnetic Suspension, Centripetal Force, Experiment, ANSYS

1 Introduction

Magnetic suspension technology is widely used in various fields in virtue of non-contact, no wear, lubrication free and long life[1,2]. Centripetal effect is a inherent property of magnetic field which is related to the structure and control system of the magnetic suspension system and has some potential applications in certain field[3,4]. Such as: magnetic heart pump, micro magnetic gyroscope and other small structures and small load applications. ANSYS has great practical significance to calculate and analyze centripetal force of magnetic field. Few researches have done in this field at present. A magnetic suspended disc is taken as an example for centripetal force calculation using ANSYS in the paper, the way of utilizing ANSYS to calculate centripetal force of the magnetic suspension disc is discussed.

2 The magnetic suspended disc system

Three electromagnets are utilized to limit *z*-axis movement and *x*, *y*-axis rotation of the disc, namely to restrict 3 degrees of freedom of the disc. And 2 degrees of freedom of the *x*, *y*-axis movement are constrained by centripetal force of magnetic field. But *z*-axis rotation is not constrained [5]. Fig.2 is the physical photo of the magnetic suspended disc system.

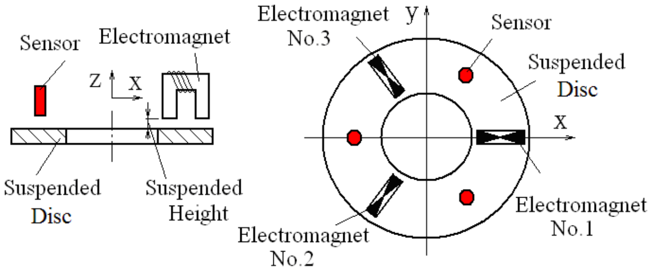


Fig.1 Schematic diagram of the magnetic suspended disc system

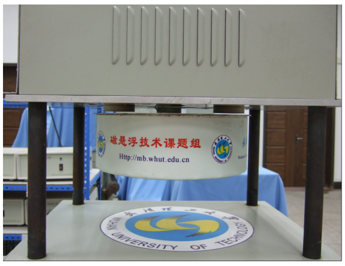
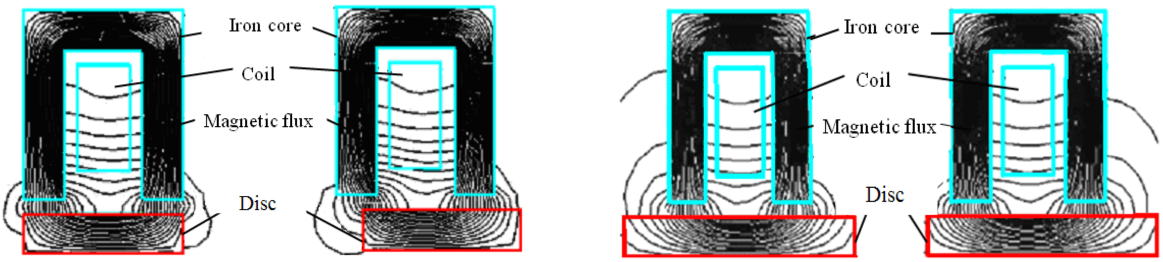


Fig.2 The photo of the magnetic suspended disc system

2.1 Relationship between centripetal effect of magnetic field and the boundary of disc

Comparing Fig.3 (a) with (b), when the boundary of disc is close to the boundary of the electromagnet, the magnetic flux on the disc changes significantly as the disc deviates, thus the centripetal effect of magnetic field is significant. While the boundary of disc is greater than the boundary of electromagnet, the magnetic flux on the disc almost remains unchanged as the disc deviates, thus the centripetal effect of magnetic field is unconspicuous.



(a)Boundary of disc is close to the boundary of the electromagnet

(b) Boundary of disc is larger than the boundary of the electromagnet

Fig.3 Relationship between centripetal effect of magnetic field and the boundary of disc

3 Centripetal force calculation using Force-Balance method

The calculation model for a single electromagnet is shown in Fig.4. The disc which is suspended steadily in a certain suspension height will deviate from the equilibrium position along the *x*-axis direction when an external force *T* is applied on along the *x*-axis direction. The force balance diagram of single electromagnet in deviation state with constant suspension height is shown in Fig.5.

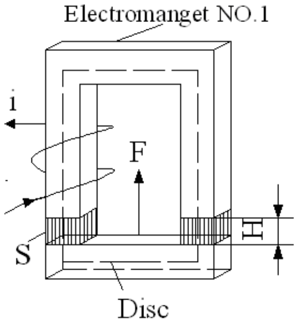


Fig.4 Single electromagnet model

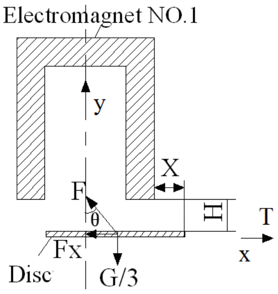


Fig.5 Single electromagnet model in deviation state

Where:

X is the offset of the disc deviates along the *x*-axis positive direction;

i is the control current in electromagnet coil;

F_x is the centripetal force acted on the disc;

F is electromagnetic force of the single electromagnet;

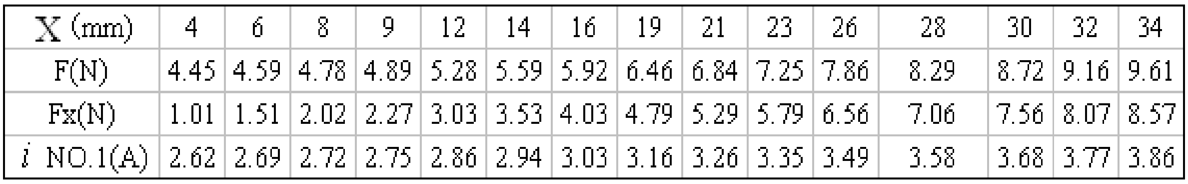
S is the cross-sectional area of the electromagnet;

G is gravity of the disc.

According to equation $F=\mu_0 N^2 S i^2/4H^2$ [6] the electromagnetic force of the single electromagnet can be calculated. It must meet the equation $F=(F_x^2+(G/3)^2)^{½}$ for force balance when the disc deviates, (The disc is suspended by three electromagnets in the magnetic suspended disc system, so here G/3), under the condition of magnetic leakage is ignored, the equation $F=G/3\cos\theta$ and $F=\mu_0 N^2 S i^2/4H^2$ are used for the control current calculation.

In calculation, actual parameters of magnetic suspended disc system are adopted: number of turns N=1630, cross-sectional area $S=0.000196\text{mm}^2$, the suspension height H=15.93mm, thickness of disc t=2.5mm, gravity G=13N. Table1 shows the calculation results of centripetal force by use of Force-Balance method.

Table 1 Calculation results using Force-Balance method



X (mm)	4	6	8	9	12	14	16	19	21	23	26	28	30	32	34
F(N)	4.45	4.59	4.78	4.89	5.28	5.59	5.92	6.46	6.84	7.25	7.86	8.29	8.72	9.16	9.61
Fx(N)	1.01	1.51	2.02	2.27	3.03	3.53	4.03	4.79	5.29	5.79	6.56	7.06	7.56	8.07	8.57
i NO.1(A)	2.62	2.69	2.72	2.75	2.86	2.94	3.03	3.16	3.26	3.35	3.49	3.58	3.68	3.77	3.86

4 Calculation of centripetal force using ANSYS

The process of centripetal force calculation using ANSYS is as follow. Here, the offset is same with experimental and the control current adopt experimental measurements and partly adopt recursion estimation.

4.1 Modeling and Parameters

The ANSYS 3-D modeling is obtained by a bottom-up method. The periphery air cylinder, suspended disc and silicon steel sheets are included in the modeling. The suspension height H is 15.93mm, the inner diameter of the disc is 156mm, external diameter is 302mm and the thickness is 2.5mm, the three coil turns are 1630, the permeability of silicon steel sheets and air are respectively 2500 and 1.0.

Parameters of ANSYS modeling includes two parts: 11 sets of parameters when $X\leq 26$mm are experimental measurements[7], while 4 sets of parameters when $28\text{mm}\leq X\leq 30$mm are recursion estimations based on the former 11 sets of parameters. In experiments, the disc is unstable when X >26mm, namely the control current can not be measured. In order to calculate centripetal force by use of ANSYS, the offset and corresponding control current when X >26mm is required. Recursion estimation is used to get the parameters that when X >26mm. Quadratic linear equation $y=0.0025x^2-0.0171x+1.7009$(ref. Fig.6) is used here for control current recursion estimations of No.1 electromagnet. And the control current of No.2 electromagnet and No.3 electromagnet are almost unchanged according to experimental measurements, thus the average current 2.15A and 1.92A respectively is used. ANSYS modeling parameters are listed in table 2.

Table 2 Parameters of ANSYS modeling when H= 15.93mm

Parameters of ANSYS modeling																
X(mm)	4	6	8	9	12	14	16	19	21	23	26	recursion estimation	28	30	32	34
i NO.1(A)	1.67	1.69	1.72	1.76	1.85	1.95	2.07	2.27	2.44	2.64	2.94		3.18	3.44	3.71	4.01
i NO.2(A)	2.15	2.15	2.18	2.19	2.19	2.18	2.17	2.16	2.14	2.11	2.07		2.15	2.15	2.15	2.15
i NO.3(A)	1.86	1.87	1.89	1.91	1.92	1.93	1.94	1.95	1.96	1.96	1.96		1.92	1.92	1.92	1.92

Where: *X* is offset; *i* is the control current.

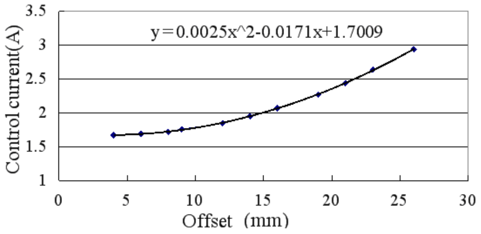


Fig.6 Control current of NO.1 electromagnet vs offset

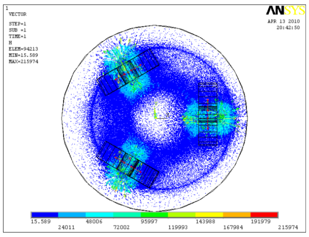


Fig.7 Vector of magnetic field density

4.2 Calculation results

According to ANSYS calculation results: Fig.7 shows that the magnetic field density vector of electromagnet NO.2 and NO.3 change relative little compared with NO.1 when *X*=16mm.

Fig.8 shows the relationship between centripetal force calculated by ANSYS and control current of electromagnet NO.1. It shows that centripetal force suddenly decreases when *X*＞28mm, which decreases two orders of magnitude compared with the centripetal force when *X*≤26mm. This is a turning point that indicates the disc is unstable.

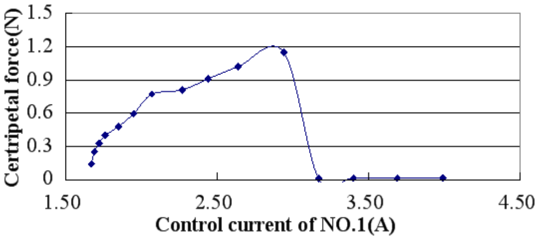


Fig.8 Relationship between centripetal force and control current of electromagnet NO.1

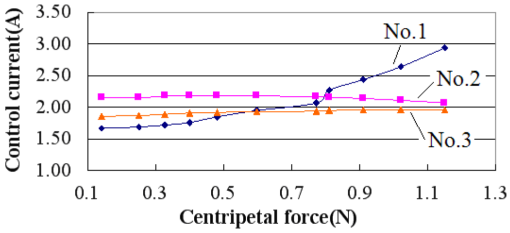


Fig.9 Relationship between control current and centripetal force

Fig.9 shows relationship between control current of three electromagnets and centripetal force calculated by ANSYS. It shows that control current of electromagnet NO.1 increases with the centripetal force, but control current of NO.2 and NO.3 change little.

5 Comparison of Force-Balance, ANSYS and experiments

Table 2 shows that control current of NO.1 electromagnet increases as the offset increases, at the same time the control current of NO.2 and NO.3 change little. That is to say the centripetal effect impact of NO.2 and NO.3 electromagnet on disc is little [8]. Thus, Fx is considered produced only by NO.1 electromagnet in ANSYS calculation, and the contribution of NO.2 and NO.3 electromagnet are ignored. In this point of view the results calculated by Force-Balance method, ANSYS and experimental measurements can be compared together.

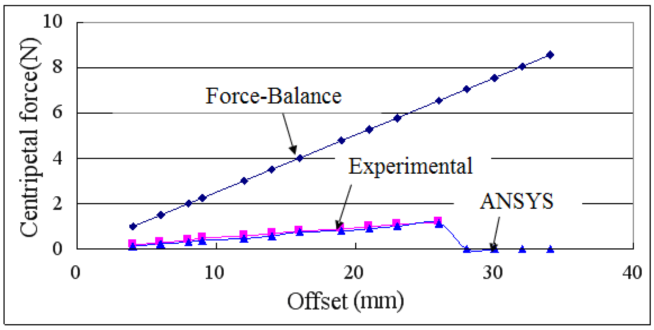


Fig.10 Comparison of centripetal force by Force-Balance, ANSYS and experiments

From Fig.10, all the centripetal force acquired by the three methods is linear. The results calculated by ANSYS match well with experimental measurements, but result calculated by Force-Balance method is not in agreement with the other methods. The disc is unstable when X >26mm in experiments. There is an obvious turning point in ANSYS centripetal force calculation around X =28mm. There is no turning point in Force-Balance method centripetal force calculation. Thus the greatest magnetic centripetal force can not found by Force-Balance method.

The reason for the result calculated by Force-Balance method is not in agreement with the other methods may be as follow: The assumptions in calculation are not well satisfied in actual circumstance, such as: small air gap, even-distributed magnetic flux and no magnetic flux leakage. However in fact the suspension height is not small enough and lead to un-ever-distributed magnetic flux; The magnetic flux leakage become more and more obvious when the disc deviates, though it is not obvious when the disc in the equilibrium position(Fig.11).

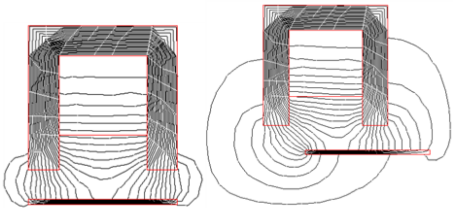


Fig.11 The magnetic flux leakage

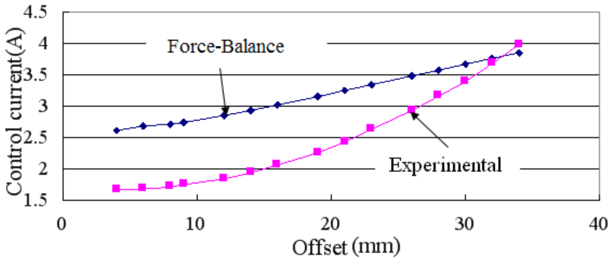


Fig.12 Control current calculated by Force-Balance Method and experimental measurements

Two dimensional simplified model used in control current calculation by Force-Balance method may be one of reasons for large error (Fig.12).

6 Conclusion

In calculating centripetal force of the magnetic suspension disc system, the control currents of the system in deviation state can be measured by experiments, under the condition the centripetal force of the system could be calculated by use of ANSYS, and the calculate results match well with the experimental measurements. And the instability critical point of the magnetic suspended disc can be distinguished from the calculate results as well.

The calculation of Force-Balance method is not applicable to calculate centripetal force of the magnetic suspension disc system, not only there is a great error in calculating the control current but also the instability critical point of the magnetic suspended system can not be distinguished from the calculate results. Thus the greatest magnetic centripetal force can not found by Force-Balance method.

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