Research on the Distribution of Permanent Magnetic Field in the Magnetic Drive of High-Speed Maglev Circular Knitting Machine

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Abstract. Research in high-speed maglev knitting drive, through the magnetic and magnetic field analysis of electromagnetic and permanent magnet hybrid drive, establishing the mathematical model of the permanent magnet external magnetic field. Based on theoretical calculation of permanent magnet external magnetic induction, and compared with Gauss meter measured data, its theoretical model calculations and experimental data are consistent. In this paper, the study is focusing on a new maglev knitting driving mechanism, which will have theoretical and practical reference significance on the latter part of knitting equipment drive way and needle selection structure.

Introduction

The driven core of commonly used circular knitting machines in the market is driven by the cam taking the needle moves up and down complete knitting action. The high-speed maglev drive knitting takes electromagnetic direct-drive mode ^[1-5], not only can efficiently complete the knitting action, but also effectively reduce energy consumption and noise, and improve efficiency. The principle of electromagnetic direct-drive shown in Figure 1, energizing coil produces a magnetic field, the permanent magnet movement by the magnetic force, by controlling the coil voltage or current magnitude control the spatial position of the permanent magnet, and then complete knitting movement. The calculation of electromagnetic force is crucial, not only related to the early driving structure design, also involves the study of control methods in the late.

By Newton's third law in a closed magnetic field still holds^[6] conclusion and calculation of coil in permanent magnetic field force, getting the force of the permanent magnet in the induced magnetic

field, because of this two forces is a pair of interaction force. The force of energized coil in permanent magnetic field can be solved by ampere force, therefore the key to the solution of the electromagnetic force is the intensity distribution of the permanent magnet in outer space. The next will focus on how to solve the magnetic induction produced by the cylindrical permanent magnet in outer space, finally getting the analytical expression for the magnetic induction, using three-dimensional Gauss meter measuring the magnetic induction of the specific dimensions permanent magnet, which verify the correctness of the mathematical model.



Electromagnetic Principles

In order to solve the permanent magnet magnetic induction, we introduced the hypothesis of ampere's circulation^[7]: composition magnet the smallest unit that compose magnet is a ring current, these molecules ring current directionally arrayed at the macro shown on the N and S poles. Figure 2 (a), when the magnetic media uniformed, any adjacent pair of current elements cancel each other out, only the edge of the cross section current element has not been offset, within the macro perspective, cross section of more molecule current overall equivalent to the loop current on the edge of the cross section, as shown in figure (b).

Therefore, the calculation of permanent magnet external magnetic flux density is equivalent to seeking the induced magnetic field intensity of the permanent magnet outer cylindrical surface circular current. The calculation of the induced magnetic field strength caused by the current, using the Biot-Savart law:

$$\stackrel{\mathbf{r}}{B} = \int_{\mathcal{L}} \frac{m_0 I}{4p} \frac{dl \times \hat{R}}{R^3} \tag{1}$$

 m_0 is the vacuum magnetic permeability whose value is $4p \times 10^{-7} Tm/A$, *I* is the source current, *L* is integral path, *R* is current element pointing to the unknown point vectors, *dl* is current element.

The single energized ring is expanded to space, then calculating the magnetic flux density of the cylindrical permanent magnet produced in the space.

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Calculation and verification of magnetic induction density

For the calculation of the magnetic induction density of the cylindrical permanent magnet in space, combined with ampere molecule circulation hypothesis and Biot-Savart law, establishing mathematical model of permanent magnet external magnetic field.

Establishment of geometry model of the permanent magnet external magnetic field

Supposing that radius of the cylindrical permanent magnet is a, high is h, position in the Cartesian coordinate system is shown in Figure 3, the magnet bottom surface center as the coordinate origin,

bottom surface as xoy plane, z axis positive direction as the magnetization direction, constructing the geometrical model as shown in Figure 3. Assuming that the permanent magnet saturated magnetization and its interior uniformly magnetized, the magnet internal magnetization strength is vector \boldsymbol{M} , for the Ampere circulation hypothesis showed that: the magnets magnetic field generated by permanent magnet side closed circulation. Supposing that circulation plane magnetization density is J_s, unit is $(\frac{A}{m^2})$:

$$J_s = \nabla \times M$$

If the magnetization direction of the magnetic material do not change, and magnetization saturated, the surface

magnetic density J_s can be regarded as constant. In space a point P coordinate is $(r \cos q, r \sin q, z - z_0)$, where r and q is point Q polar coordinates that point P in the projection plane xoy. Selecting any thickness of the permanent magnet as dz_0 thin layer circulation, the z-axis axial height is z_0 . a and a is polar coordinates of the current element d1 in dz_0 thin plane. R is radius vector of the current element d1 to the point P.

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(2)





Mathematical model of permanent magnet external magnetic field

By the simple mathematical calculation and transformation of the geometric model, the formula (1) can be used to solve the analytical formula of the permanent magnet external magnetic field. The current circulation intensity is $I = J_s dz_0$ for thin layer dz_0 , field strength is dB in point P, so the general circulation produce total magnetic induction in point P is :

The analytical expression of the external magnetic field is too complicated to requirements to solve a expression, for the correctness of the formula cannot from the surface of the formulas make judgments, the following will be through experiments to judge the formula is correct. Now getting the relatively fixed point P in space, measuring different permanent magnets magnetic induction in point P. The special point P is taken as the center point of the end face of the permanent magnet, z=h, r=0. B_x , B_y and B_z are magnetic induction intensity components along x, y and z axial:

$$B_{x} = \frac{m_{0}J_{x}a}{4p} \int_{0}^{h} \int_{0}^{2p} \frac{\cos a(h-z_{0})}{\left[a^{2} - (h-z_{0})^{2}\right]^{\frac{3}{2}}} dadz_{0} = 0$$
(5)

$$B_{y} = \frac{m_{0}J_{s}a}{4p} \int_{0}^{h} \int_{0}^{2p} \frac{\cos a (h - z_{0})}{\left[a^{2} - (h - z_{0})^{2}\right]^{\frac{3}{2}}} dadz_{0} = 0$$
(6)

$$B_{z} = \frac{m_{0}J_{s}a}{4p} \int_{0}^{h} \int_{0}^{2p} \frac{a}{\left[a^{2} - (h - z_{0})^{2}\right]^{\frac{3}{2}}} dadz_{0} = \frac{m_{0}J_{s}}{2} \frac{h}{\sqrt{a^{2} + h^{2}}}$$
(7)

From the above formula shows that in the center of the permanent magnet B_x and B_y value is 0, the value of B_z is determined by the permanent magnet shape and density of magnetization. Using the experimental data, the reverse calibration of magnetic density value, you can determine whether the analytical formula is correct.

Gauss measured

Gauss meter is a precision instrument which measuring the magnetic flux density at a point in space. Using Gauss meter measuring the magnetic induction of a particular point in sample space, and anti-analyze the J_s value in the formula. This experiment used NdFeB permanent magnet materials, and it has been in the magnetic saturation, the magnetization direction in the axial direction, so the samples should have the same J_s value.

The experimental samples divided into five groups, each group composed of five permanent magnets which each diameter and height were 8 * 2,5 * 2,4 * 2,4 * 3 and 4*4, through measuring the center plane of the permanent magnet, we can concluded:

<u>1</u>		1		U											
	First 8*2			Second 5*2			Third 4*2			Fourth 4*3		Fifth 4*4			
	(mm)		(mm)			(mm)			(mm)			(mm)			
B (mT)	B _x	By	Bz	B _x	By	Bz									
1	1.3	5.5	152	1.5	2.3	195	9.2	8.6	237	12.8	1.6	279	13.6	6.8	305
2	0.5	4.2	161	1.6	2.4	199	7.7	4.4	244	13.3	16	269	11.7	9.2	309
3	3.2	0.3	172	12.1	4.3	204	10.2	7.8	248	13.7	6.9	280	11.1	1.8	305
4	1.5	0.5	170	8.0	4.4	202	6.1	1.7	244	4.1	7.7	281	18.4	7.3	302
5	1.3	1.7	168	5.7	0.8	198	11.2	4.2	240	5.6	0.6	281	8.9	9.8	306
Average	1.6	2.4	165	5.8	2.8	200	8.9	5.3	243	9.9	6.6	278	12.7	7	305

From the experimental data we can concluded, in each experiment X, Y direction of the magnetic flux density is much less than the Z direction value, taking into account the measurement errors, processing and Magnetizing errors of the permanent magnet, the measurement overall consistent with the formula expression basically. Through the formula (7) launched the magnetization density:

Combined with survey data, J_s value can be calculated:

$$\mathbf{J}_{s} = \frac{2\mathbf{B}_{z}\sqrt{a^{2}+h^{2}}}{m_{0}h} \tag{8}$$

The J_s value can be calculated by combining the measured data:

	First 8*2	Second 5*2	Third 4*2	Fourth 4*3	Fifth 4*4	
	(mm)	(mm)	(mm)	(mm)	(mm)	
$Js(\times 10^5)$	5.872	5.095	5.469	5.318	5.427	

Seen in the above table, J_s value fluctuations are not very obvious, this fully demonstrates that our calculation of analytical expression for the magnetic field can be applied to practical, laid the theoretical foundation for future research.

Conclusion

Taking the new high-speed Maglev knitting round machine for research object, with amps molecular circulation hypothesis derived the analytical expression of the permanent magnet outer space magnetic induction, and using the existing high-precision Gauss meter to measure several samples of magnetic induction, comparing the measurement results and analytical results, both results consistent, proving the correctness of the proposed calculation method of magnetic induction, which laid the groundwork for further theoretical calculation of electromagnetic force in the future.

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