Magnetic field Analysis and Parameters Calculation for Two-Degree-of-Freedom Direct Drive Induction motor

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This paper employs analytical method to analyze electromagnetic field and calculate parameters of two-degree-of-freedom direct drive induction motor (2DOFDDIM) with solid rotor coated with copper layer taking the radial nonlinear magnetic permeability of solid steel into consideration. The 2D electromagnetic field multi-layer model was established. The specific method dealing with parameters determination needed by multi-layer iterative utility program was proposed to calculate the equivalent circuit parameters of solid steel. The propagation constant was introduced to calculate parameters of copper layer. A complete 2DOFDDIM stratification method diagram was provided and the accuracy of analytical method is verified with comparison to finite element method.

***Index Terms*—two-degree-of-freedom (2DOF), analytical model, electromagnetic field, equivalent circuits, propagation constant, solid rotor**

I. INTRODUCTION

Two-degree-of-freedom (2DOF) motor, which produces rotary, linear and helical motion, is widely utilized in industrial machinery such as boring machines and grinders [1]. There are a few different constructions of 2DOF motor [1]-[4]. Si Jikai proposed a two-degree-of-freedom direct drive induction motor (2DOFDDIM) shown in Fig.1 [5]. The stator consists of an arc-shape rotary and linear armature placed oppositely one another. One generates the rotating magnetic fields, while another produces traveling fields. A common rotor coated with thin copper layer is applied.

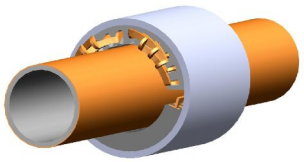

Fig. 1. Model of 2DOFDDIM

On account of its sophisticated structure, the electromagnetic field and equivalent circuit parameters cannot be determined accurately just applying equivalent magnetic circuit method or equivalent magnetic impedance method Jacek. F. Gieras proposed an analytical method to design and analyze double-layer solid-motor applying simple multi-layer theory [6]-[7]. Tang Xiaogao used multi-layer theory to analyze the solid unslotted rotor induction machines [8]. Although a few scholars has studied solid rotor using multi-layer [4],[9], there is no specific method to deal with parameters determination needed by multi-layer iterative procedure of solid-rotor induction motor coated with copper layer. So this paper investigated 2DOFDDIM applying an analytical method which combines specific multi-layer theory with propagation constant method. The accuracy of analytical method is verified with comparison to finite element method.

II. ANALYSIS AND CALCULATION

The rotor of 2DOFDDIM is divided into a number of laminar regions of arbitrary thickness and different material characters, as shown in Fig.2.

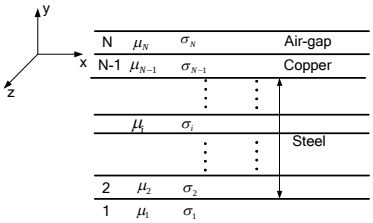

Fig. 2. Multi-layer model of the rotor of 2DOFDDIM

Where the air-gap and copper are set as the outermost layer and secondary outer layer respectively. Regions 1~*N*-2 are layers of solid steel. $\mu_i, \sigma_i, \omega_i$ are permeability, conductivity, angular frequency of each layer，(*i*=1,2,…,*N*-2). The *x*-axis is circumferential direction, the *y*-axis is the radial direction and the *z*-axis is axial direction. The transfer matrix of electromagnetic field is conducted combining Maxwell's Equation with boundary conditions [8], as shown in (1).

$$\begin{bmatrix} B_{yi} \\ H_{xi} \end{bmatrix} = \begin{bmatrix} ch(\gamma_i b_i) & \frac{1}{\beta_i} sh(\gamma_i b_i) \\ \beta_i sh(\gamma_i b_i) & ch(\gamma_i b_i) \end{bmatrix} \begin{bmatrix} B_{yi-1} \\ H_{xi-1} \end{bmatrix} \quad (1)$$

where $\gamma_i = (a^2 + j\omega_i \mu_i \sigma_i)^{1/2}$, $\beta_i = \gamma_i / (ja\mu_i)$, $a = \pi / \tau$, τ is pole pitch, b_i is layer thickness， H_{xi} and B_{yi} are tangential magnetic field intensity and radial magnetic flux density of *i* layer respectively.

The specific method to determine parameters in iterative procedure such as the optimum layer number, layer thickness, layer permeability, condition of convergence and so on is proposed. The electromagnetic field distribution in solid steel are conducted. The equivalent circuit parameters of solid steel are calculated adopting wave impendence.

There is a bigger error and more difficult to converge applying multi-layer theory to analyze copper layer on account of the particularity of 2DOFDDIM. So the propagation constant is imported to calculate the equivalent circuit parameters of copper layer [6], as shown in (2).

$$Z_{cu} = \frac{j\omega_{cu}\mu_{cu}}{K_{cu}} \frac{1}{K_{cu} d_{cu}} \frac{L}{\tau} \quad (2)$$

Where K_{cu} is propagation constant, d_{cu} is the thickness of copper layer, ω_{cu} is angular frequency of copper layer, μ_{cu} is copper permeability, L is axial length of the rotor.

Based on the related theory above, a complete 2DOFDDIM stratification method is given, which is shown in Fig.3.

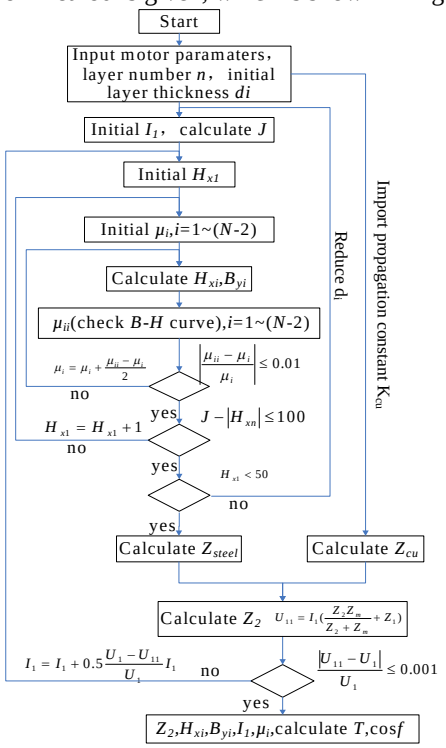

Fig.3. A complete 2DOFDDIM stratification method diagram

III. DISCUSSION

Because the linear motion part can be equivalent to rotary one, only the rotary motion part of 2DOFDDIM is established, as shown in Fig.4. The change curve of tangential magnetic field intensity and radial magnetic flux density along radial direction, torque, current, power factor and other motor parameters are derived. The results of analytical method and finite element method are compared. The change of radial magnetic flux density and torque are shown in Fig.5 and Fig.6. The others will be analyzed in the future paper.

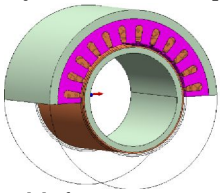

Fig. 4 The finite element model of rotary motion part of 2-DOFDDIM

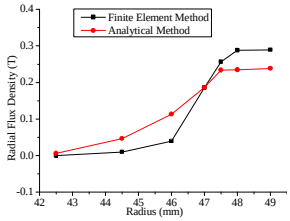

Fig. 5 The curve of radial magnetic flux density

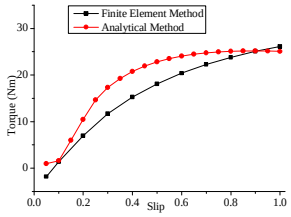

Fig. 6 The curve of torque

It can be seen that the analytical results coincide good with finite element results. The error will be decreased in the future work.

IV. CONCLUSION

The specific method dealing with parameters determination needed by multi-layer iterative procedure was proposed to analyze electromagnetic field of solid steel. The propagation constant was imported to calculate parameters of copper layer, which improve the accuracy of the analytical method. The presented specific analytical method of 2DOFDDIM was verified with finite element results, which can be recommended for the study of the motor.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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