Analysis of Printed Rotor Winding DC Motor with Analytical and 3D Finite Element Method

Sun-Ki Hong, and Bum-Hoon Kim
Dept. of System & Information Eng., Hoseo University
Asan, ChungNam, 336-795, KOREA
skhong@hoseo.edu, rmftp1234@gmail.com

Abstract — Printed rotor winding DC motor doesn't have iron core and only has copper winding, therefore it has very small inertia and high speed response. However it becomes very difficult to analyze this motor with FEM because it should be solved by 3-D FEM and its structure is very complex. In this paper, this motor is analyzed for the steady and transient states with analytical method at first. Because the rotor winding structure is very difficult, 1 or 2 coil patterns are analyzed by 3D FEM according to the electric angle for half period. After that, those results are composed and the motor torque can be calculated. This result is compared with the analytical method and the appropriateness of the proposed method is conformed.

I. INTRODUCTION

DC motor is widely used not only in the industry but in home appliance. DC motor is classified to radial flux type motor(RFM) and axial flux type motor(AFM [1-3]). In many cases, AFM is coreless type [4] and coils are located perpendicular to the shaft direction. Because the coils are parallel to the permanent magnet, the axial direction length of this motor is relatively shorter than that of RFM. For the coreless motor, the moment of inertia is small and the motor is advantageous for acceleration and deceleration. If the radius increases, the horizontality of the rotor coil can be deformed and if the thickness of the coil increases, the magnetic air-gap increases and the magnet strength should be increased. Recently, high performance motor with high acceleration, short axial length for low volume is required. Printed rotor winding DC motor (PRWDCM) is a kind of AFM and it can satisfy the requirements. However, the rotor structure of the motor is very complex and is not easy to analyze or design.

In this work, the steady and transient state analyses for the PRWDCM were performed. A transient motor model is developed for the analysis of the PRWDCM and a finite element analysis is also executed. For the FEA of this kind of motor, 3D analysis is necessarily required because of the structure of the PRWDCM. Especially, the rotor structure is very complex and the rotor winding is not be able to be departed according to the pole-pair period. Therefore it becomes to require time and memories to solve the motor with the full model. Therefore a simple analysis method is proposed. That is, the coil is separated into its basic pattern and the motor is solved for each pattern and after that the results are composed and the motor torque can be calculated. The results of this new approach to analyze this motor are compared with specification of the sample motor and good agreements are achieved.

II. BASIC STRUCTURE OF PRWDCM

There are big differences between the common brush DCM and the PRWDCM. For the stator, it is not so different with the common AFM, however for the rotor side, there doesn't exist iron core for low weight and low inertia, the copper wire pattern is made with the same process of PCB and the number of layers is from 2 to 8. To fix the rotor pattern, the process may be same with the PCB. In other way, the pattern is fixed through the epoxy molding. The rotor disk is located between the stator magnets.

A. Stator shape

Fig. 1 shows the 3D structure of the PRWDCM stator. The number of poles is 8 and the poles of each back iron are opposite to each other. The both back irons become the magnetic path of the magnetic flux. The rotor plate is installed in the gap between the magnets and the rotor shaft rotates in the center hole of the back iron plates.

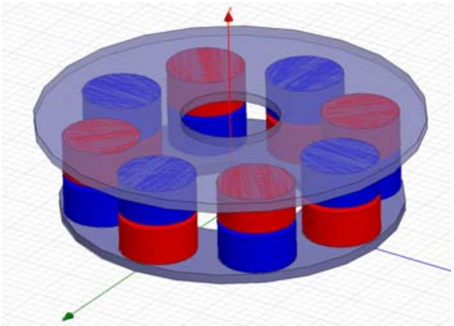

Fig. 1. The stator shape of the PRWDCM

B. Rotor shape

Fig. 2 shows the shape of the rotor plate. The conductors are constructed with 4 layers and each layer is isolated with epoxy. As mentioned before, there is no iron core, so the rotor has low inertia and low mechanical time constant, this motor is very good at acceleration and deceleration.

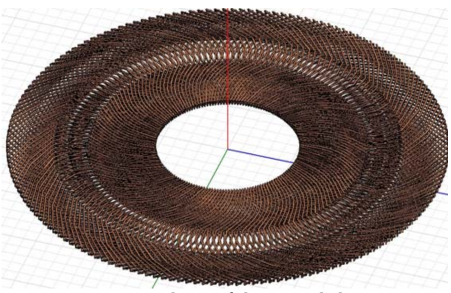

Fig. 2. 3D shape of the rotor disk.

III. ANALYSIS OF THE MOTOR CHARACTERISTICS

A. *Calculation of the magnetic flux density*

Magnet can be selected according to the motor requirements. Ferrite magnet may need large volume, rare earth magnet may need high cost. From these reasons, Alnico magnet is most preferable because it is durable and has high flux density although it has low coercive force. From the cross point of the operating line and the fitted curve of the B-H demagnetization curve data, the magnetic flux density can be calculated

B. *Transient analysis of the motor characteristics*

With the electrical and mechanical equation of (1) and (2), the sample motor is simulated.

$$V_t = R_a i_a + L_a \frac{di_a}{dt} + K_e \omega_m \quad (1)$$

$$T_D = K_t i_a = J_m \frac{d\omega_m}{dt} + B_m \omega_m + T_L \quad (2)$$

Fig. 3 shows the transient model from (1) and (2). In the figure, R_I parameter shows the no load loss resistance which can consider the difference between the real and idealized model. Fig. 4 shows the simulation results of the current and speed response of the sample motor which are well matched with the specification.

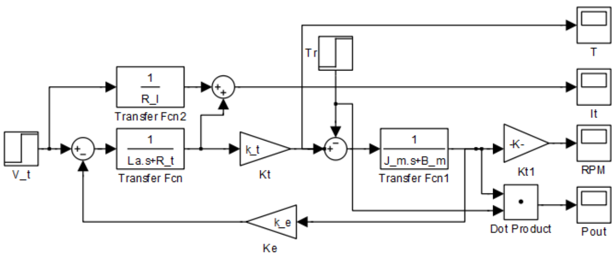

Fig. 3. PRWDCM transient model considering no load loss.

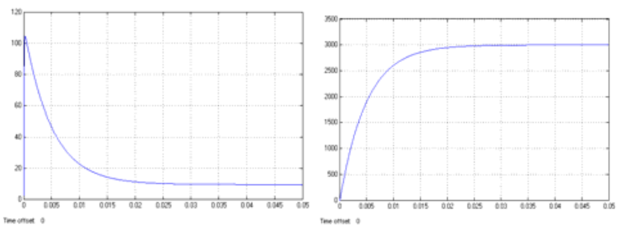

Fig. 4. Armature current and motor speed waveforms.

TABLE I. Simulation results of sample motor

	Specification	Simulation	Unit
Back EMF constant	39.0	39.0	V/krpm
Rating speed	3,000	3,010	Rpm
Rating torque	3.3	3.3	Nm
Rating current	9.5	9.51	A
Rating output	1,036	1,040	W
Developed output	3.5	3.49	Nm

C. *Torque analysis by 3D FEA*

It is impossible to analyze the PRWDCM with 3D FEM because of its 3D structure. In addition, the rotor winding is very complex as shown in Fig. 2. In this work, this motor is analyzed for each pattern of the winding. Fig. 5 shows the 1 pattern of the rotor winding. Fig. 6 shows the calculated torque values for each pattern and the results were synthesized to get the motor torque and the developed torque has good agreement with the motor specification.

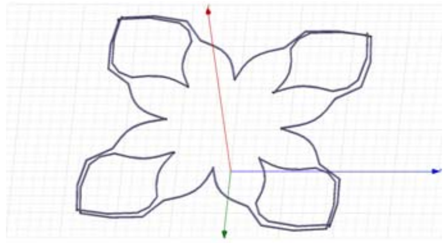

Fig. 5. 1 pattern of the rotor winding.

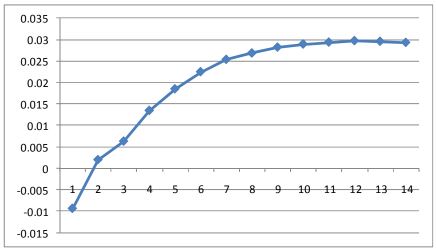

Fig. 6. Calculated torque values for each pattern

IV. CONCLUSION

The inertial of PRWDCM is very low and this motor has high speed response because PRWDCM doesn't have iron core in the rotor. In this work, the transient state characteristics were analyzed and 3D FEA was also executed for high precision analysis because of the motor structure. PRWDCM has complex 3D rotor structure and is not possible to be solved with period condition. In this work, the rotor was analyzed with each pattern to reduce the number of mesh elements and the each result was synthesized to get the motor torque. The calculated results are compared with the specifications of the sample motor and good agreements were achieved for the PRWDCM.

V. REFERENCES

[1] C.C. Chan, "Axial-field electrical machines design and applications", IEEE Transaction on Energy Conversion Vol. EC-2 No.2, June 1987

[2] J. Fred Eastam, "Novel Axial Flux Machine for Aircraft Drive : Design and Modeling", Magnetics, IEEE Transactions on Vol. 38, Sep 2002

[3] S.M. A. Sharkh and M. T. N. Mohammad, "Axial field permanent magnet dc motor with powder iron armature," *IEEE Transactions on Energy Conversion*, vol. 22, Sept. 2007.

[4] N. Lombard and M. Kamper, "Analysis and performance of an ironless stator axial flux pm machine," *Energy Conversion, IEEE Transaction on*, vol. 14, pp. 1051–1056, Dec 1999.