

TRANSIENT ANALYSIS OF A BLDC STARTER/GENERATOR SYSTEM USED IN ELECTRIC VEHICLES

Xinli Xu¹, Yan Shi^{2,*}, Anbo Liang³, Ming Zhang⁴, Qian Liu¹

¹ College of Engine & Electronic Engineering, Qingdao Agricultural University, Qingdao, China., 266109

² College of constructional engineering, Qingdao Agricultural University, Qingdao, 266109,China

³ International Intercommunion School, Qingdao Agricultural University, Qingdao, China, 266109

⁴ College of Electric and information Engineering of Jiangsu University of Science and Technology Zhen Jiang 212013, China

* Corresponding author, Address: Foodstuff Science and Engineering college, Qingdao Agricultural University, 700 Changcheng Road, Qingdao, 266109, P. R. China, Tel:0532-88030446, Email: shiyan517@163.com

Abstract: The brushless DC motor used in ISAD of Electric and Hybrid Electric Vehicles is introduced in this paper. Magnet field distribution and static characteristic of permanent magnet brushless DC motor are calculated by finite element methods.

Keywords: Integrated Started Alternator Damper, Static and dynamic characteristic, Permanent brushless DC, Finite element method

1. INTRODUCTION

Integrated Started Alternator Damper is a new technique which has been used in auto's framework in recent years. The electric motor of ISAD integrates starting motors and generators, so it can lighten auto's weight, save space and reduce the cost. Not only can this system realize Regenerative Braking, but also can provide accessional start/brake function,

what's more, it can boost engine's torque when necessary. All this system can promote the efficiency of the system, export more electrical energy, reduce the cost of auto's energy, and tail gas and noise(Yin Wei et al.2006).

Instead of the mechanical commutate of normal direct current electrical motor's brush and commutator, brushless DC motor makes use of electrical commutator. It has many advantages, such as higher running efficiency, none excitation cost, good timing function, and so on(Jianzhong Sun et al.2005). And the rotor of brushless motor is made of permanent magnet steel. As the rare-earth permanent material has high magnetic energy product, it can reduce the weight of the motor, spare the volume of the motor, which can do good to auto and motorcycle's start/generating system which has limit weight and volume for the installation's place and using method. The usual magnetor of start/generating system is permanent magnet synchronous motor, which can be reformed easily to be the start/generating motor for its framework as similar as the brushless DC motor(A Permanent Magnet Brushless DC Motor Problem). And the block diagram of the framework of brushless DC motor is as follows (Fig.1):

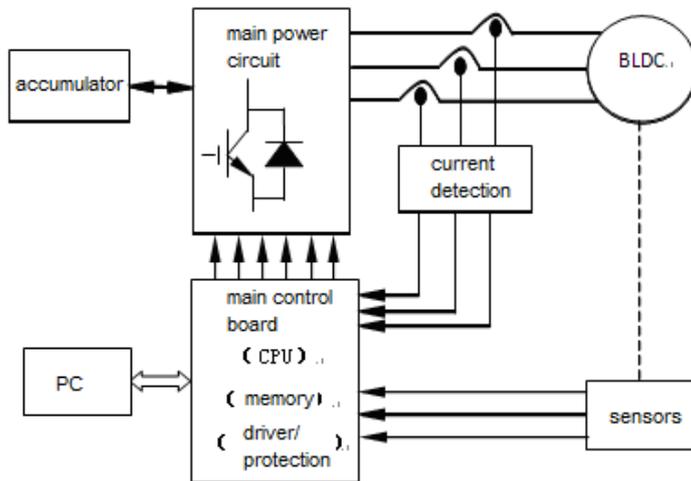


Fig.1. The block diagram of the framework of brushless DC motor

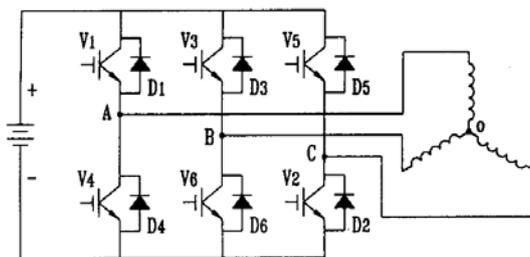


Fig.2. The main circuit of brushless DC motor

2. THE BASIC EQUATION OF BRUSHLESS DC MOTOR

This paper makes use of star connection-three-phase bridge main circuit in which each two phase bridge energizes to each other. That's to say, there are two power pipe being broken over every moment, and phase changes every 1/6 cycle, each phase changes one power pipe and every power pipe breaks over 120° electrical angle. As Fig.2 shows. The voltage equation of brushless DC motor can be simplified as:

$$U_s - 2U_T = E + 2rI_a \tag{1}$$

U_T ——the voltage drop of switch apparatus

E ——the back elevation of motor

I_a ——Armature Current

Any has the two-phase winding to lead at any time all,

As for three phase-six mode brushless DC motor, two phase winding will be lead at any time , so the back elevation of the motor is:

$$E = 2E_m = \frac{2pW_\phi}{15a_l} \phi_\delta n = C_e \phi_\delta n \tag{2}$$

C_e ——electromotive force constant of the motor, $\frac{2pW_\phi}{15a_l}$

ϕ_δ ——flux of each electrode, Wb, $\phi_\delta = B_\delta \alpha_i \tau L_a$

W_ϕ ——Number of turns of each phase's cascade of armature winding
the electric current of armature winding:

$$I_a = \frac{U_s - 2U_T - E}{2r} \tag{3}$$

At each moment, motor's electromagnetic torque is formed by the interact of two-winding's composite magnetic field and rotor field:

$$T_e = \frac{2E_m I_a}{\Omega} = \frac{EI_a}{\Omega} = \frac{4pW_\phi}{\pi\alpha_i} \phi_\delta I_a = C_T \phi_\delta I_a \tag{4}$$

Ω ——mechanical angular velocity of rotor, $\Omega = 2\pi n / 60$

C_T ——Torque constant of the motor, $C_T = \frac{4pW_\phi}{\pi\alpha_i}$

3. ESTABLISH THE MODE

Firstly, we should design the framework of the motor and import the basic data and main size to Ansoft's Rmxprt, then we can get the two-dimension Finite Element Model of the motor(Guoqiang Liu et al.2005). Main parameters of brushless DC motor's mode are as follows: voltage rating:220V, power rating 1.5KW, rotate speed 3176r/min, load 4.5N.m, moment of inertia $0.00112825\text{Kg}\cdot\text{m}^2$. The Finite Element Model of the motor is as Fig.3 shows. The Skewed Stator Slot I use can reduce the cost of brushless DC motors, lower the noise and vibration and improve the stationarity of motors(Renyuan Tang.1997).

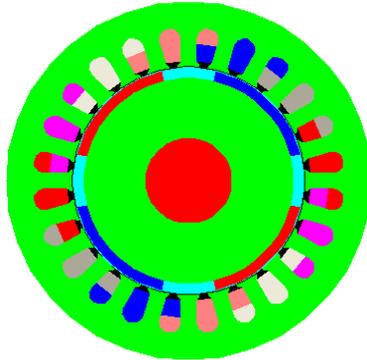


Fig.3. Finite Element Model of brushless DC motor.

The most valid method to study the motor's Transient Behavior is time-stepping finite element method, which has high degree of accuracy for it can involve every factor of the motor, such as: slot effect, skewed slot effect, saturation effect, vortex, skin effect and so on. Then defining the characteristic of each subdivision part of the mode and subdividing the grid are done. When frequency changes, system can change the part automatically and realize adaptive subdivision. If the grid is broken, and the broken is big enough, then the air gap can subdivide the grid anew. After subdividing the grid, we should assure proper Boundary Condition and load. Boundary Condition adopts the natural boundary, and excitation source adopts the additional voltage source which is controlled by rotor's place. As Fig.4 shows, S1-S12 are switches controlled by V1-V6, and V1-V6 are functions of place, whose delay angle is 60° electrical angle one by one. Then defining the parameter of count process is done, such as counting march, time, accuracy and the process parameter.

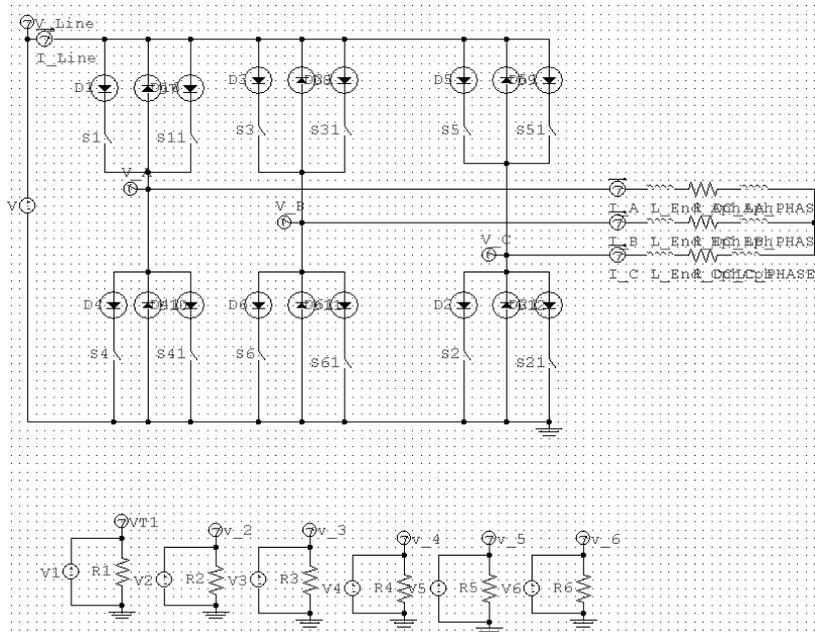


Fig.4 Simulation by the Canadian circuit

4. PROCESS OF EMULATION ANALYSIS

4.1 Analysis of static character

Through analyzing the motor’s magnetic field, Ansoft can test the shape, size and Rotor Laminations’ size. What’s more, it can make the motor’s function be the best through adjusting some parameter of the motor. Fig.5 shows the distribution of rotor’s magnetic line of force when motor idle loads. Fig.7 shows circle distributing curves of flux density. We can see that the flux density and magnetic line of force is well-distributed along the circle, which indicated that the design of the motor is reasonable. Fig.6 and Fig.8 shows the distribution of rotor’s magnetic line of force when motor loads, which is different from Fig.5 and Fig.7, that’s because the magnetic field of armature winding affect the main magnetic field when motor loads, which is also called armature reaction. The main effect of q-Axis Armature’s magnetomotive force to airspace magnetic field is changing the distribution of airspace magnetic field. Armature reaction lies on the degree of saturation

of magnetic circuit, the changing of motor, connecting style of armature winding and electrifying mode of inverter.

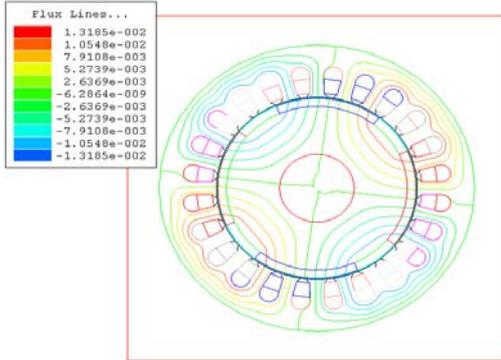


Fig. 5 the distribution of motor's magnetic field when idle loads

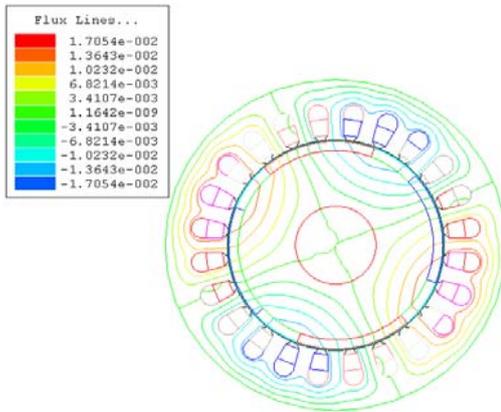


Fig. 6 Distribution of motor's magnetic field when loads

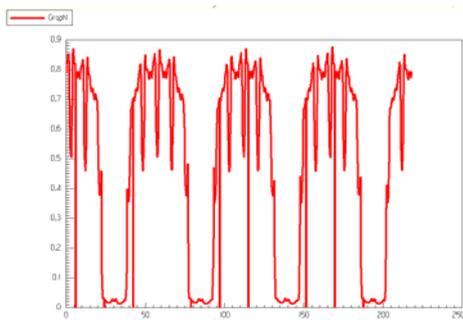


Fig.7 Distribution of motor's air gap flux density when idle loads

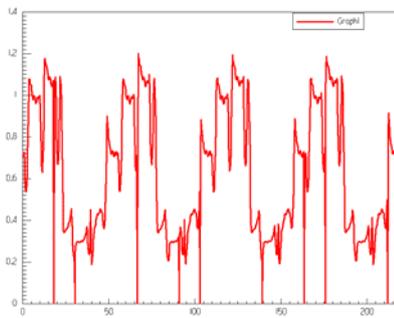


Fig.8 the distribution of motor's air gap flux density when loads

4.2 Analysis of dynamic character

ISAD system requires the smallest synthetic starting torque when the motor starts should be greater than the biggest load torque of the motor's engine. The author makes use of Ansoft's transient soft and counts the motor's starting, loading and other transient process. The results are as the diagram below, including electric current, torque, speed and power cost's varying curves along with time. As the turning inertia of the motor is small, so the motor will be stable after starting 0.04s when loading running. At 0.3s, the motor's loading is adjusted suddenly, when $t < 0.3s$, $T_L = 4.5 \text{ N}\cdot\text{m}$; when $t > 0.3s$, $T_L = 6 \text{ N}\cdot\text{m}$; when $t = 0.3s$, the load change suddenly. At this time the motor overloads, the rotate speed declines and the torque increases, however, the motor which the the author designs can still run stably, so the function of the motor which the author designs is stable.

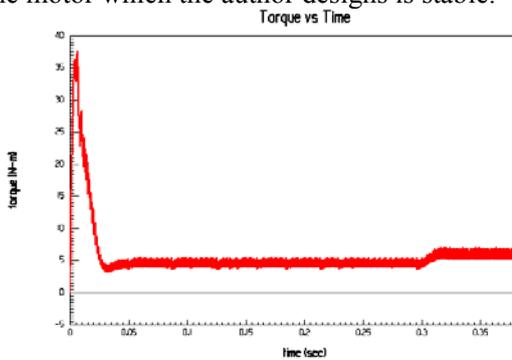


Fig. 9 Changing curves of the torque when the motor starts.

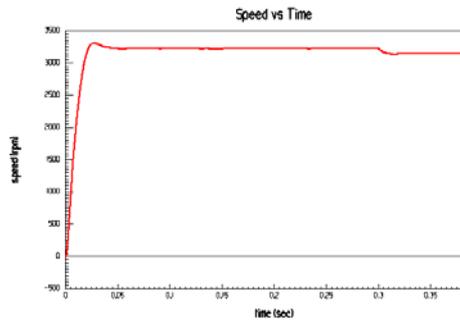


Fig. 10 Changing curves of rotate speed when the motor starts.

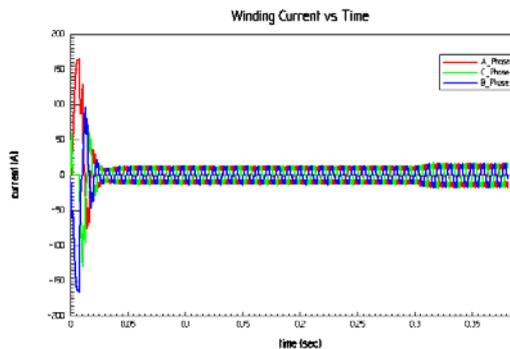


Fig. 11 Changing curves of three-phase winding current when the motor starts

5. CONCLUSION

We can see from the diagrams that the brushless DC motor designed by the author which has application in mixed-power auto's starting generating system has many advantages, such as: torque's pulsation is small, the starting torque is big which is about 10times of the rating torque, the efficiency is 90% and it is stable at low speed. But one point should be concerned, when the motor starts, as for its low speed, the electromotive force which caused by rotor flux cutting stator winding is very little, so the starting electric current may be over the rating current. To solve this problem, we should add current-limiting circuit. We can see from Fig.10 that there is torque ripple caused by commutation current delay which is affected by winding inductance when communicating. We can adopt commutation method by overlap and optimal current control to reduce torque ripple.

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