Simulation and Analysis Calculation of PMBLDCM Based on Time-Stepping Finite Element and Matlab Methods

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Abstract. A time stepping finite element analysis model coupled circuit field and movement used in analyzing permanent magnet brushless DC (BLDC) motors is presented in this paper. Taking into account the whole permanent magnet brushless DC motor system, taken terminal voltage as input quantity, transient electromagnet field of a 50W six poles permanent magnet brushless DC motor was calculated and simulated. Then, the back electromotive force was put into the model of Matlab. Finally the results from two methods were compared, and simultaneously some good conclusions were drawn.

Introduction

Permanent-magnet brushless DC motor (BLDC) is widely used in various fields of precise electronic instrumentation and equipment, industrial automation, and modern household appliances. In particular, since the NdFeB permanent magnet materials have been used into commercial production, low-power brushless DC motor (PMBLDCM) has been widely used[1], the performance analysis, design, and control strategy of the brushless motor has become a hot issue in the motor areas. Depth study on the relationship between structure and dynamic performance, the motor will be used in such research and development of the theoretical basis for actual production.

There is a very different dynamic performance between the brushless motor and electric motor, so the simulation of the dynamic performance of the motor is very important before the parameters were designed [2].

Time stepping finite element analysis

This paper takes the permanent magnetic BLDC motor of 50W as an example for analysis, and its operation works at two-phase electric star-connected three-phase six state. Figure 1 shows the system diagram [3]:

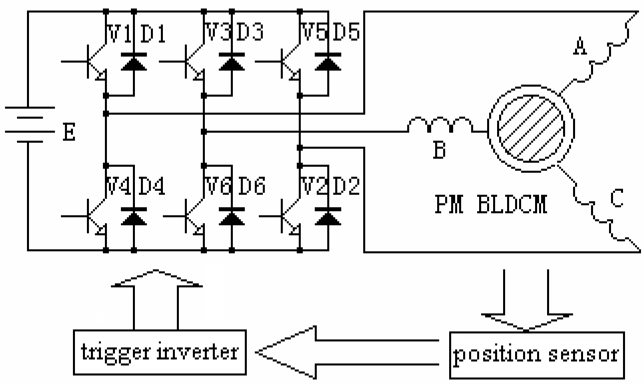


Fig.1 The configuration of permanent magnetic BLDC motor

The stator winding of the permanent magnetic BLDC motor is concentrated winding. It is a hypothesis that the magnetic field of BLDCM is homogeneous distribution along the axial direction, and the two-dimensional field analysis method is used. Only the Z component of the magnetic vector potential is existed. Eddy current and magnetic hysteresis loss in the rotor iron core are neglected, the equations of electromagnetic field and electric circuit of the electrical machinery should be satisfied following relations:

$$\begin{cases} \frac{\partial}{\partial x}(\nu\frac{\partial A}{\partial x})+\frac{\partial}{\partial y}(\nu\frac{\partial A}{\partial y})+J=0 & (\Omega) \\ \nu_1\frac{\partial A}{\partial n}-\nu_2\frac{\partial A}{\partial n}=J_m & (\Gamma) \\ [e]+[i][R_1]+[L_\sigma]\frac{d}{dt}[i]=[u] & \end{cases} . \tag{1}$$

In the formula: Ω is the domain of solution, Γ are the borders of the permanent magnet and other media, J_m is the equivalent current density of the permanent magnet, J is the current density of the winding.

If working in single current intervals and when the A and C phases are all leading simultaneously, the values are followings:

$$[e]=\begin{bmatrix} e_a-\frac{e_a+e_c}{2} \\ 0 \\ e_c-\frac{e_a+e_c}{2} \end{bmatrix},\quad [u]=\begin{bmatrix} u_a \\ 0 \\ u_c \end{bmatrix}. \tag{2}$$

In the formula (1), induced voltage is the critical parameter combining the stator region magnetic field and the electric circuit. The value of A-phase induced voltages is shown in following:

$$e_a=-\frac{d\Psi_a}{dt}=-\frac{d}{dt}\left(\frac{NL_{ef}p}{aS_b}\sum_{i=1}^{n}\alpha_a\Delta_e\frac{A_i+A_j+A_m}{3}\right). \tag{3}$$

In the formula: Ψ_a is the winding flux linkage of A phase, L_{ef} is the effective length of the electrical machinery, n is the total number of units, p is the number of the pole pairs, Δ_e is the elemental area, A_i, A_j, A_m are the magnetic vector potentials of the three nodes of the triangle unit. The induced voltages of the other two phases can be also obtained by the same principle.

Finite element discrete equation is founded by the weighted residual method; the weight function is equal to the shape function. Making the equation of electromagnetic field discrete in formula (1) and coupling the equation of stator electric circuit, the total equation can be obtained. The spatial and the time discrete system equation can be obtained by replacing the differential with the time difference.

Then, taking the power supply voltage and the leader conduction angle as the input variable is feasible and reasonable. Combining the equation of electromagnetic field with the inverter control circuit, adopting the time-stepping finite element method, the operation characteristics of the electrical machinery are gained. The finite-element meshing diagram on a certain position is given in figure 2. Figure 3 shows the distribution diagram of Magnetic line on rated condition corresponding to figure 2.

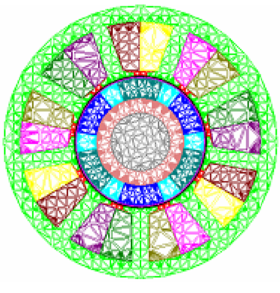


Fig.2 Finite-element meshing diagram

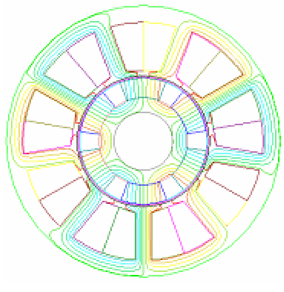


Fig.3 Distribution diagram of Magnetic line

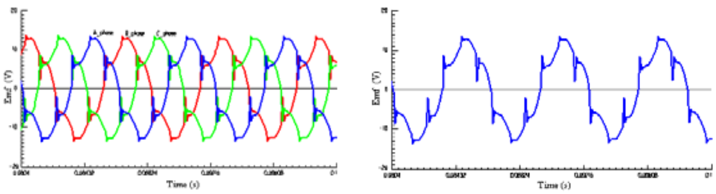
Electric motor model establishment

A 50W six pole permanent magnet brushless DC motor is taken as the research object in this paper, the parameters is shown in Table 1.

Table 1 Design details of the prototype

Rated power	50 W	Rated voltage	24 V
Rated current	3 A	Rated speed	3350 r/min
Number of slots	9	Number of poles	6
Stator outer diameter	56 mm	Rator outer diameter	26 mm
Airgap length	0.5 mm	Stack length	60 mm

It can be established the motor model based on field circuit coupled time-stepping finite element, the analysis of motor performance is carried on. At rated load conditions, the simulation curves of the phase winding electromotive force, current and torque related with the time are shown in Figure 4 to Figure 6.



(a) A, B, C three-phase (b) A phase

Fig.4 Anti-voltage waveform

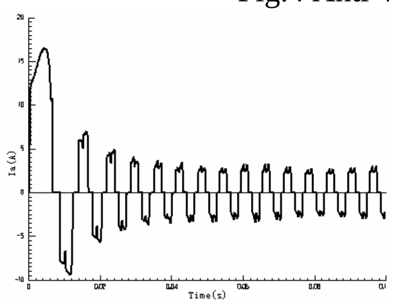


Fig.5 Current waveform of the A-phase

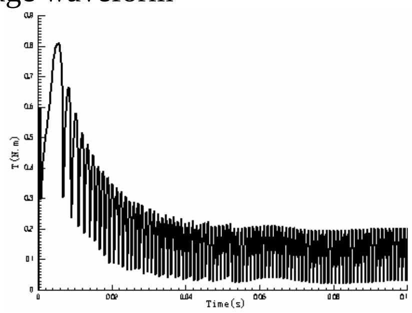


Fig.6 Simulated torque waveform

The current waveform because of the effect of the current commutation is not completely square, but a certain jagged distortion from the figure 4 and figure 5 showed. The anti-EMF waveform is an approximate trapezoidal wave and the pulses are produced at the current changed. From the figure, the current and the back EMF are the synchronism on the phase, so the current torque of the motor can get the maximum value of units. The fluctuations curve of the electromagnetic torque is showed in figure 6.

Back EMF based on finite element simulation of Matlab

The simulation model is shown in figure 7.

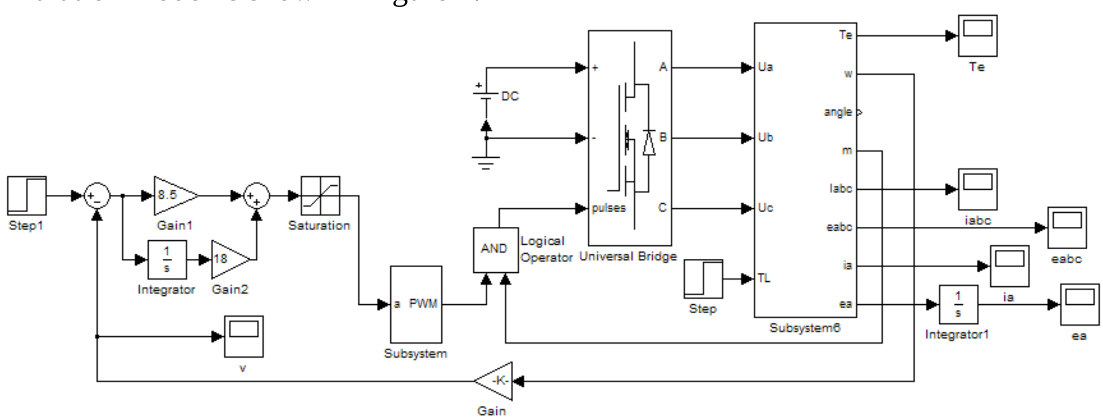
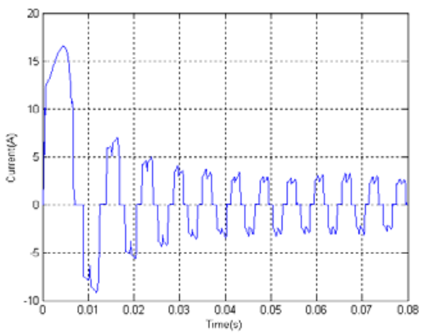


Fig. 7 Simulation model of PMBL DC motor system

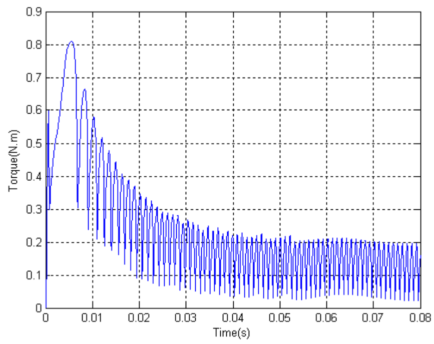
The body module is taken as a key in the simulation model of the entire system. The module is to strike the three-phase current according to the voltage equation. In order to obtain the three-phase current i_a, i_b, i_c, the three opposite force e_a, e_b, e_c must first be obtained, and the self and mutual inductances of the three-phase winding are also be obtained. The self and mutual inductances of the motor phase winding are calculated based on the energy method[4].

Striking a trapezoidal back EMF is the most critical in BLDCM modeling process. The back EMF waveform will directly affect the amount of motor torque ripple and current waveform [5]. The field-circuit coupled time stepping finite element method is used in this paper. According to a certain time step, every step of the calculation in accordance with steady-state field is calculated to get the motor parameters under the corresponding time .

The three opposite force shown in figure 4 is put into Matlab system model to obtain the current waveform and torque curves. By comparing figure 5 and figure 8, the size and shape of the current waveform from the two methods are basically same. While it can also be seen from the figure 6 and figure 8, that the electromagnetic torque waveform got from the two methods is consistent with each other.



(a) Current waveform of the A phase



(b) Electromagnetic torque waveform

Fig. 8 Current and torque waveforms

Conclusion

The field-circuit coupled time-stepping finite element method is used, the terminal voltage is taken as the input in the field-circuit coupled time stepping finite element method, the current iteration is eliminated, and the calculation becomes simple and accurate results can be obtained. The current and torque waveforms got from the Matlab/Simulink simulation of PMBLDCM by the back-EMF waveforms obtained by the finite element, is basically the same waveform of the waveforms through the field-circuit coupled time stepping finite element method. It accurately reflect the performance of the motor load process, and has some significance on further optimization and design of the permanent magnet brushless motor.

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