Design and Analysis of a Brushless DC Machine for a Miniature Battery Electric Vehicle

XiaodongSun[1,2], Zhou Shi[1], Xing Xu[1,2], Zebin Yang[3], Ke Li[3], Jianguo Zhu[4], and Youguang Guo[4]

[1] School of Automobile and Traffic Engineering, Jiangsu University, Zhenjiang 212013, China, xdsun@ujs.edu.cn
[2] Automotive Engineering Research Institute, Jiangsu University, Zhenjiang 212013, China
[3]School of Electrical and Information Engineering, Jiangsu University, Zhenjiang 212013, China
[4]School of Electrical, Mechanical and Mechatronic Systems, University of Technology, Sydney, Sydney, NSW 2007, Australia

An electrical and mechanical design process for a Brushless DC (BLDC) machine in a miniature battery electric vehicles application is studied in this paper. The design process of a BLDC machine needs close cooperation between various engineering disciplines The key of the designed machine is parameter matching which needs the road conditions and vehicle parameters are well combined and calculated. In addition, by using the finite element analysis (FEA) method the cogging torque and electromagnetic torque of the designed machine is simulated to prove its performance.

***Index Terms*—Electric vehicle, BLDC machine, finite element analysis, electrical machine design.**

I. Introduction

It is an urgent need for research and development of advanced electric drive system for electric vehicles (EVs). Among all types of machine drives, the brushless DC (BLDC) mahine are the most attractive machine drives for EV so far. High power density and high efficiency are their notable features, which is attributed to the use of high-energy pemanent magnet (PM) material [1].

This paper deals with a BLDC machine for a miniature battery EV. In Section II a design process where a machine having a max rotating speed of 4200 min^{-1} and a rated power of 6 kW is designed by taking the electrical and mechanical performances into consideration. The electromagnetic performance of the proposed BLDC machine is analyzed by using the finite element analysis (FEA) method in Section III. The conclusion is shown in Section IV.

II. Parameter Matching and Design

A miniature battery EV was designed for the daily use in Zhenjiang. The speed and torque requirements were investigated for this EV application by recording the road condition. The highest torque demand, good voltage regulation over wide-speed generation, and the demand for maximum speed are the primary design parameters [2]. The parameter values of the miniature battery EV are given in Table I. The rate power and the machine speed can be calculated from these values.

When the EV is running at a constant speed in a horizontal road the power of the machine P_e can be expressed as

$$P_e = \frac{1}{\eta_T}\left(\frac{Gfu_a}{3600} + \frac{C_D A u_a}{76140}\right) \quad (1)$$

where η_T is the mechanical efficiency of transmission system, G is the total gravity of the EV, f is the rolling friction coefficient, C_D is the air drag coefficien, and A is the front cross sectional area. In the case of having P_e and u_a, the torque (T_{tq}) and rotational speed (n) required by the machine at a certain u_a can be given by

$$u_a = 0.377\frac{rn}{i_g i_0} \quad (2)$$

$$P_e = \frac{T_{tq} n}{9550} \quad (3)$$

where r is the radius of the wheel and the i_g is the transmission ratio. The main parameters of the machine can be calculated by using the parameters in Table I and are given in Table II.

TABLE I
Miniature Battery EV Parameters

Parameters	Symbol	Value
Total mass of the EV	M	900kg
Front cross sectional area	A	2.1m^2
Air drag coefficient	C_D	0.34
Rolling friction coefficient	f	0.015
Radius of wheel	R	275mm
Final drive fixed gear ratio	i_{diff}	8.83

Table II
Main Parameters

Parameters	Value
Work Voltage	300 V
Rate/ Peak Power	6/18 kw
Max Torque	90 N.m
Max Rotating Speed	4200r/min

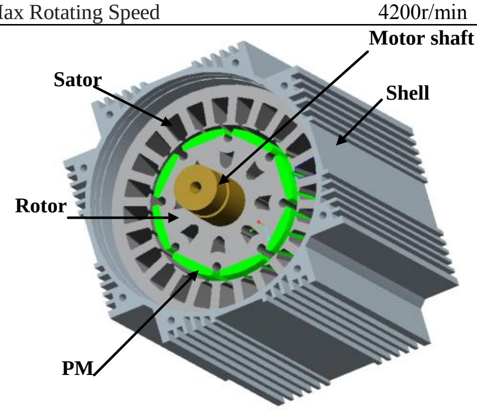

Fig. 1. Structure of the BLDC machine.

Here the BLDC machine is designed for a certain operation, the required size and weight should be designed suitable for the EV. The Structure of the BLDC machine is shown in Fig 1.

Although the BLDC has the characteristics of high efficiency and high power density, the development of the BLDC machine is limited by the expensive PM material. Therefore, it is essential to use as little of the PM material to reduce the cost without sacrificing the machine performance.

The ratio of the stator inner diameter to the stator outside diameter is another significant design parameter for BLDC, because it is closely related to the torque capability and efficiency.

III. Performance Analysis

The FEA method is used to analyze the performance of the proposed machine. Various parameters of the BLDC machine such as the cogging torque, flux linkage, back electromotive force (EMF) and output torque will be calculated. Fig 2 shows the mesh plot of the FEA model and magnetic field distributions of the proposed machine.

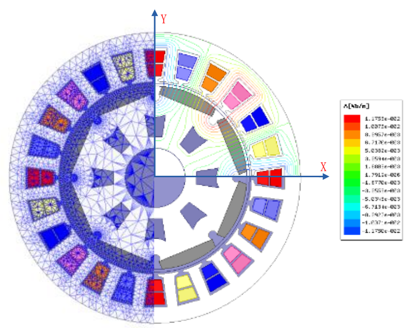

Fig. 2. Mesh plot and Magnetic field distributions of the proposed machine.

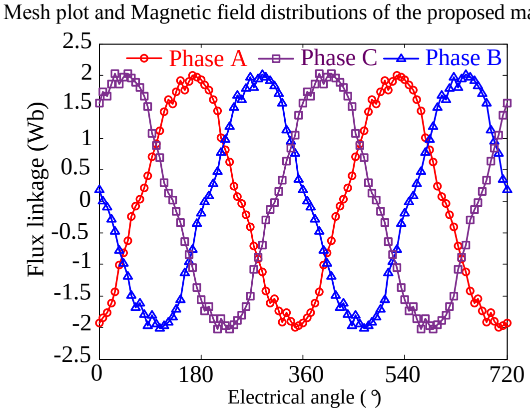

Fig. 3. Flux linkages of the proposed machine.

Fig.3.shows the PM flux linkage. It can be seen that the flux linkage waveform is basically in accordance with the sine distribution. The three phase EMF waveform of proposed machines is shown in Fig 4. According to Fig 4, the EMF waveform transforms two cycles with rotor making half revolution, and it also shifts 30 mechanical degrees between phase to phase, which fulfills

$$e = \frac{d\Psi_{PM}}{dt} = \frac{d\Psi_{PM}}{d\theta} \cdot \frac{2\pi n}{60} \tag{4}$$

where e represents EMF, Ψ_{PM} is PM flux linkage, n is machine speed, and θ is the electrical angle.

For BLDC mahcines, the power and torque can be respectively expressed as follow

$$P_e = e_a i_a + e_b i_b + e_c i_c = 2E_m I_m \tag{5}$$

$$T_e = \frac{P_e}{\omega_r} = \frac{2E_m I_m}{\omega_r} \tag{6}$$

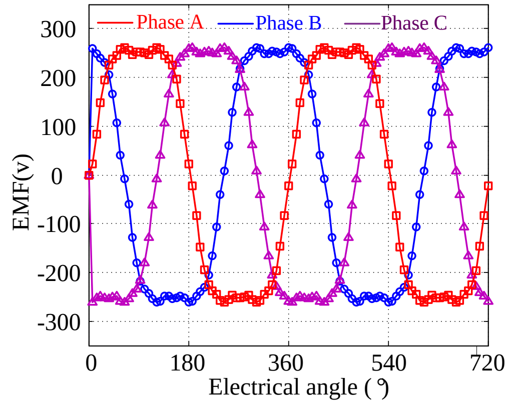

Fig. 4. Back EMF waveforms of the proposed machine.

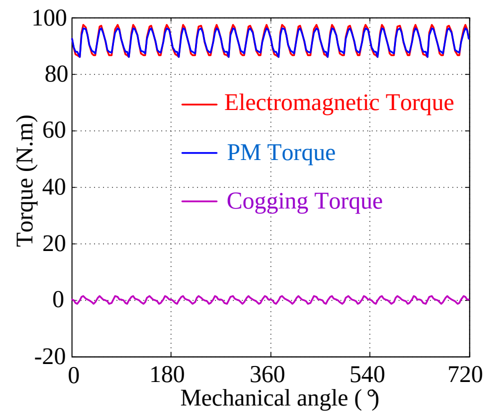

Fig. 5. Torque waveforms of the proposed machine.

When the input current is 30A, the electromagnetic torque is shown in Fig. 5. We can see that the cogging torque only accounts for a very small part of the electromagnetic torque from Fig.5. Moreover, the torque meets the requirements of the miniature EV.

IV. Conclusion

A BLDC machine for a miniature battery EV has been designed in this paper. Parameter matching of the machine is made by calculating the values of the road condition and the specific values of the miniature EV. The performance of the machine is simulated by the FEA which meets requirements of the design. The prototype is being manufactured to verify the correctness of the simulation and some further researches will be done to improve the design.

References

[1] K. T. Chau, and C. C. Chan, "Overview of Permanent-Magnet Brushless Drives for Electric and Hybrid Electric Vehicles," *IEEE Transactions On Industrial Electronics*,vol. 55, No. 6, June 2008.

[2] Pia Lindh, Mohammad Gerami Tehrani, Tuomo Lindh, Jan-Heri Montonen, Juha Pyrhonen, Juiss T. Sopanen, Markku Niemelä, Yulia Alexandrova, Paula Immonen, Lassi Aarniovuori, and Lassi Aarniovuori "Multidisciplinary Design of a Permanent-Magnet Traction Machine for a Hybrid Bus Taking the Load Cycle into Account," *IEEE Transactions on Industrial Electronics,* 2016. 63(6): p. 3397-340.