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Analysis of BLDC Motor for Electric Vehicles

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Abstract – Nowadays electric vehicles are replacing conventional vehicles because of their environment friendly operation and less maintenance. Most of the electric vehicles use three phase induction motors. In this project BLDC motor drive is proposed as it exhibit high torque, high efficiency, easy speed control, reduced noise and longer life time. Retrofitting conventional vehicles to electric vehicles by replacing a brushless dc motor will have a great scope in future as it is economical. Then, choosing air gap length, permanent magnet thickness and the number of stator winding turns as variables, parametric analysis was made to research the influence of structural parameters on system efficiency and the torque-current ratio. After an optimization design, a prototype was fabricated and tested. The test results show that the optimized prototype can meet the need of the driving system both in constant torque region and constant power region.

Index Terms –Electric Machine, Hybrid electric vehicle, BLDC motor

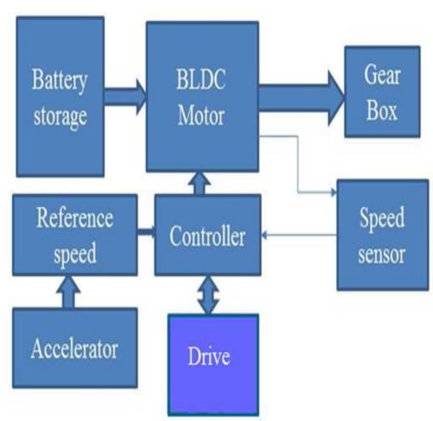
1. INTRODUCTION

Electric vehicles are at least twice as efficient as conventional vehicles. So we are encouraging more electric vehicles than conventional vehicles. In this system an idea of retrofitting the conventional vehicles to electric vehicles is proposed. A BLDC motor drive and its controller can be designed as per the weight and torque specifications on existing conventional vehicles. This will reduce the cost because existing conventional vehicles are transformed to electric vehicles with required specification. BLDC motor is proposed because it has high torque, high efficiency, reduced noise, easy speed control and longer lifetime.

As the name suggests brushless dc motor does not have brushes and they are commuted electronically. With the development of economy and productivity, more and more energy-saving products enter markets and are widely used in the industry and the lives of people. Rare-earth permanent magnet brushless DC motor is such a new energy-saving electrical machine, which has the merits of small volume, light weight, high efficiency, low rotary inertia, highly control precision. It also has good mechanical character as common DC motors, so as to be suitable for adjustable-speed drive applications, for example, the electric vehicle (EV) drive systems.

Compared with the surface magnetic structure, the interior magnetic structure is more reliable with higher mechanical strength and better anti-demagnetization ability, and can extend the field-weakening operation area [4-9]. Based on the above understanding, this paper designed an interior permanent magnet brushless DC motor (IPM-BLDCM) for a pure electric car and studied the influence of design parameters on the motor performance.

BLDC motors are known for their high durability due to simplicity in design and high rpm capabilities. They have both small and large applications. The motor is controlled by a motor controller. The motor controllers need rotor position to control the motor. Some type of controllers uses Hall Effect sensors or rotary encoder to sense the rotor position. Others measure the back emf in the undriven coils to infer the rotor position. It contains three output terminals which are controlled by logic circuits. Advanced controllers use microcontroller to manage acceleration and speed.



The BLDC motor is energized by lead- acid battery. Accelerator consist of a varistor. The varistor output wills according to the acceleration and this output will fed to the controller. The signal from the accelerator is the reference signal. The hall sensors mounted on the BLDC Motor will provide the actual speed of the motor. These two signals are compared in the controller and the power output from the chopper drive is varied. The signal from the chopper is fed back to the motor. According to the power output from the chopper drive the motor speed can be controlled.

2. RELATED WORK

2.1 MACHINE DESIGN SPECIFICATION

The configuration of the investigated interior PM brushless machine is shown in Figure 1, where a V-type flux-focusing rotor structure, which is similar to the rotor structure of the Toyota Pruis, is adopted. However, different from the distributed winding structure of the motor in the Toyota Pruis, fractional-slot concentrated modular windings are newly employed in the investigated interior PM brushless machine. The coils which belong to each phase are wound on consecutive teeth, which are conducive to a high copper packing factor and to reducing the copper loss due to relatively short end windings. Additionally, the cogging torque can be significantly reduced without the use of skew. Such a modular machine can exhibit a high inductance, since the energy that is associated with fundamental magnetomotive force (MMF) and other lower-order space harmonics is stored in the magnetic field rather than being converted into mechanical energy. Thus, constant power operation can be achieved for this investigated PM brushless machine over an extended speed range.

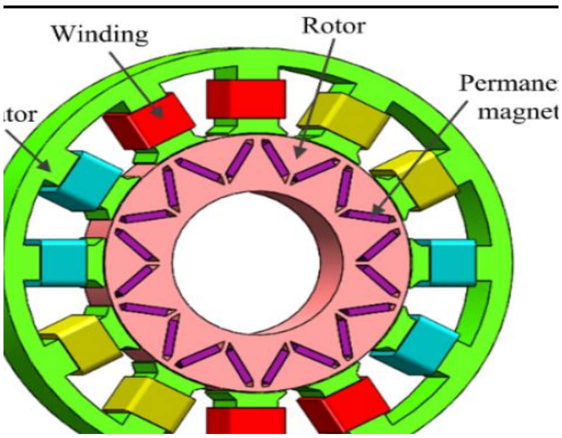


Figure 1. Configuration of the interior permanent magnet (PM) brushless machine.

BLDCM system for EVs should have a good power characteristic with constant torque drive below base speed and constant power drive above base speed [2, 10-12]. Thus, the parameter matching of motor and vehicle must be done based on the driving performance analysis of the vehicle, in order to determine appropriate technical indexes like rotational speed and torque for the motor.

The rated speed of the IPM-BLDCM is determined based on the economical vehicle speed, and the rated power is corresponding to the driving power required for travelling horizontally at the maximum constant speed. The peak torque is usually 2~3 times of the rated torque, according to the gear design of the vehicle. Furthermore, in this paper under the consideration of overall performance, cost, operation economy and other factors, the main performance indexes of the motor were determined, as listed in Table 1.

Tab. 1 Main performance indexes of the motor

Index Name		value	unit
rated voltage	U	154	V
rated power	P	10	kW
rated rotational speed	n	3000	rpm
rated torque	Tem	32	Nm
maximum power	Pmax	24	kW
maximum torque	Tmax	80	Nm

In this case, an I-type interior permanent magnet rotor is used for the motor, and both magnetic circuit method and finite element method are adopted to get a simple, compact and reliable structure design. Figure 2 shows the 3D structure of the IPM-BLDCM, without considering the casing, the end covers, the position sensor and some relevant mechanical connection parts. The motor adopts 2 pole-pairs, 24 slots, and three-phase star connected single-layer winding.

The stator slot type and the winding connection are shown in Figure 2 and 3. The stator and rotor core are laminated of insulated silicon steel sheets, the DW470-50. Samarium cobalt magnet YXG -30H is used in this case, as it has good thermal stability. The preliminary design for the main structures and sizes of the IPM-BLDCM are listed in Table 2.

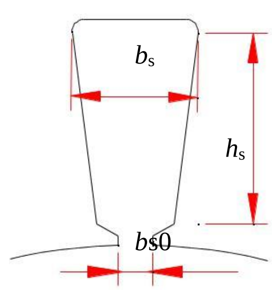


Fig. 2. The stator slot type.

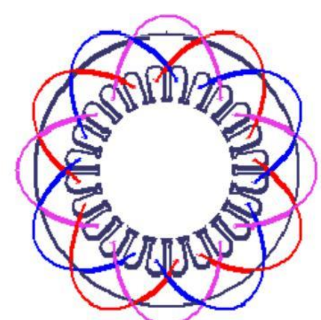


Fig 3. The winding connection.

Tab. 2 Preliminary design of the IPM BLDCM

Parameter Name		value	unit
outer diameter of stator		170	mm
inner diameter of stator		100	mm
air gap length		1.0	mm
number of stator slots		24	
	bs0	3	mm
dimension of stator slot	b_s	11	mm
	h_s	16	mm
tooth width		6.8	mm
number of parallel branches		4	
number of conductors per slot		21	
outer diameter of rotor		98	mm
inner diameter of rotor		50	mm
core length		135	mm
thickness of magnet		5	mm
width of magnet		55	mm
mechanical pole embrace		0.83	
width of magnetic bridge		2.0	mm

3. PORPOSED MODELLING

3.1: ANALYSIS OF THE MOTOR PERFORMANCE WITH DIFFERENT DESIGN PARAMETERS

Tab. 3 Parameter settings of comparison schemes

Parameter Name	S1	S2	S3	S4
air gap length (mm)	1.0	0.7	1.0	1.0
PM thickness (mm)	5	5	7	5
number of conductors per slot	21	21	21	19

The influences of structural parameters on the motor performance were studied by parametric analysis. Once the main dimensions are determined during the design process, the variable parameters can only be confined to air gap length, magnet size and number of winding turns, etc. Four schemes were chosen for contrastive research on the basis of the preliminary design, and the parameter settings of comparison schemes 1 to 4 (S1~S4 for short) are shown in Table 3.

A. The influence of air gap length on the motor performance

Contrastive analysis was investigated by only changing the air gap length, that is, scheme 1 and 2 in Table 3 were compared. The analysis results are shown, which respectively represent the contrast curve of output torque, efficiency and the torque-current ratio.

B. The influence of PM thickness on the motor performance

By only changing the thickness of permanent magnets, scheme 1 and 2 were compared and analyzed. The contrastive analysis results including the output torque, efficiency and the torque-current ratio are shown in the form of curves.

C. The influence of number of the stator winding turns on the motor performance

By only changing the number of stator winding turns, or more specifically, the number of conductors per slot, scheme 1 and 4 were compared and analyzed. The contrast curves of output torque, efficiency and the torque-current ratio are shown in Figure 13 to 15.

3.2 ANALYSIS OF THE MOTOR PERFORMANCE INFLUENCED BY DIFFERENT LOAD RATES

The actual driving conditions of the electric vehicles are usually rather complex, so the motor cannot keep a specific operating state. That is, the load rate is always changing constantly. Investigating the motor performance at different load rates is helpful to comprehensive evaluate the design quality.

Different torque characteristics were chosen for analyzing in this paper. As shown in Figure 16, characteristic curve 1 to 3 represent the torque that changes with speed respectively under the conditions of overload, rated and light load. Three curves of efficiency and torque-current ratio change with the load ratio are obtained, as shown in Figure 17 and 18.

It is evident from Figure 16 to 18 that the motor performances at different load rates show great differences. The motor efficiency increases with the increase of speed at any load rate, while the highest efficiency appears in the range of lower than the rated speed under overload, near the rated speed under rated load, and above the rated speed under light load. At the same speed, the motor efficiency has a higher value under the rated load, which indicates that the selection of rated point of the motor is reasonable in this design.

4. CONCLUSION

The BLDC Motor of high power rating is not available easily. When compared with other motor, cost of BLDC motor is really high. BLDC Motor and it's controller should be matched to each other. Coupling the motor with the gear box of the existing vehicle was tiresome and time consuming. The influences of air gap length, PM thickness and the number of stator winding turns on system efficiency and the torque-current ratio were analyzed. Contrastive analysis of performance at different load rates was implemented to consider the complex operating conditions of electric vehicles.

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