ELECTROMAGNETIC INVESTIGATION OF EXTERIOR ROTOR V-SHAPE PERMANENT MAGNET MOTORS FOR E-SCHOOTERS BY A FINITE ELEMENT TECHNIQUE

KHẢO SÁT ĐẶC TÍNH ĐIỆN TỪ CỦA ĐỘNG CƠ NAM CHÂM VĨNH CỬU KIỂU V ROTO GẮN NGOÀI CHO XE MÁY ĐIỆN BẰNG PHƯƠNG PHÁP PHẦN TỬ HỮU HẠN

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ABSTRACT

In this paper, an exterior rotor V shape permanent magnet motor of 2kW is investigated to improve the constant torque and power in a wide speed in comparison with the conventional BLDC motor. This outer rotor of permanent magnet V shape motor of 2kW is potentially applied for E-scooters of the VinFast Group - Vietnam with the speed of 90km/h. Several topologies of stator slots/permanent magnet poles are proposed to obtain the maximum motor power, torque and efficiency. The main advantages of V shape permanent outer rotor are produced with the high number of rotor pole such as Z36/p32 and Z48P40 to keep a small back electromagnetid force still at the high speed. In this paper, an auto design program is presented to find out permanent magnetic parameters and winding size though many calculation loops. The magnetic flux density, eletromagnetic torque and torque ripple can be also estimated by Matlab coupling to a finite element method.

Keywords: *Exterior permanent magnet motor, E-scooters, electromagnetic torque, Finite Element Method.*

TÓM TẮT

Trong bài báo này, động cơ nam châm vĩnh cửu xếp chữ V 2kW rôto ngoài được nghiên cứu để cải thiện khả năng giữ mô-men xoắn và công suất không đổi ở tốc độ rộng so với động cơ BLDC hiện tại. Loại động cơ rô to ngoài nam châm chữ V nam 2kW này sẽ rất triển vọng ứng dụng cho xe Escooter của Vinfast - Việt Nam có tốc độ 90km/h. Một số bộ cấu trúc rãnh stato/cực nam châm vĩnh cửu được thiết kế để tìm ra kết cấu có công suất, mô-men xoắn và hiệu suất lớn nhất. Ưu điểm chính của rôto ngoài vĩnh cửu hình chữ V là do có có số cực rôto cao như Z36/p32, Z48P40 và kết cấu nam châm gắn chìm nên có thể giữ cho sức điện động nhỏ ở tốc độ cao qua đó giữa cho mô mem không đổi ở vùng tốc độ. Trong bài báo này, một chương trình thiết kế tự động nhằm tìm ra các thông số kích thước nam châm vĩnh cửu và kích thước dây quấn thông qua nhiều vòng tính toán. Mật độ từ thông, mômen điện từ và mômen đập mạch cũng được khảo sát thông qua chương trình tính bằng Matlab liên kết với phương pháp từ tính phần tử hữu hạn.

Từ khóa: *Động cơ nam châm vĩnh cửu rotor gắn ngoài, xe hai bánh, mô men điện từ, phương pháp phần tử hữu hạn.*

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1. INTRODUCTION

An exterior rotor has been recently proposed for the E-bike brushless DC motor [1-4]. It is a simple structure to easily mount a permanent magnet (PM) on the rotor body. This is to provide an exterior rotor V-shape permanent magnet (PM) motor for the sport motor bicyle design of in-wheel motor as an electric scooter in Vietnam (Figure 1). Currently, several companies are developing electric motors for electric motor bicyles such as VinFast, HK bike, small start-up Dat-Bike and Selex motors [1-4]. Among those developers, Vinfast motor bicycle V9 model is equipped with a mid-engine and chain transmission system with a power of up to 7100W. It can reach a power of 9000W equivalent to 12HP and a maximum torque of 22.27Nm. This power helps V9 accelerate from 0 to 70km per hour in just six seconds and reach a maximum speed of 90km/h. Up to now, the maximum torque, power and speed of the electric motor for mid-drive power trains have been presented in Table 1. Those companies are also the imported BLDC motors with the inner or outer rotor structures from commercial products such as the QS/Golden Motor in China.

Figure 1. Electric motorcycle model development of VinFast [1]

In [5], the V-shape interior permanent magnet (IPM) machine is found to have a lower cost than an synchronous permanent magnet (SPM) machine when the same torque performance is required. In [6-8], a novel permanent-

magnet flux switching machines with various-shaped magnets, including rectangular magnets, wedge-shaped magnets, and V-shaped magnets, are investigated and designed for in-wheel traction application.

In this paper, an outer rotor of V shaped PM motor is designed to get the maximizing torque and power in a wide arrange speed up to 6000rpm. Geometry parameters of the outer V shaped PM motor for the above scooter parameter are shown in Table 2.

Table 1. Specifications of E Scooter

No	Voltage	72VDC
1	Rated power	5kW
2	Peak power	7.5kW
3	Speed	3000 - 5000rpm
4	Rated torque	13Nm
5	Peak torque	45Nm
6	Efficiency	>88%
7	Weight	Weight
8	Number of Pole	4
9	Packing Size	380x310x280mm

Table 2. Geometry parameter of V shaper outer rotor

No	Parameters	Value	Unit
1	Outer diameter of rotor	110	mm
2	Inner diameter of rotor	88	mm
3	Air gap	0.5	mm
4	Stack length	100	mm
5	PM sizes	1.5x12	mm
6	Shaft diameter	40	mm

2. ELECTROMANGETIC DESIGN

An analytical design program of V shape IPM motor is implemented by the Matlab coupling to the CAD drawing. Main blocks of the design program are shown in Figure 2.

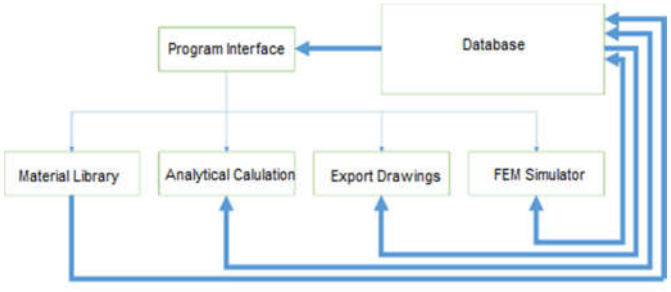


Figure 2. Diagrammatic program

The program is split into three main parts: a process of analytical calculation, an exporting drawing and the magnetic simulation. There are also some supporting parts including material library which also associate with the finite element method (FEM). Many analytical steps have been implemented to defined the torque, and electromagnetic parameters as:

$$T = \frac{\pi}{2} D^2 . L_{stk} . \sigma . TVR \quad (1)$$

where T is the electromagnetic torque (N.m), D is the rotor diameter (mm), L_{stk} is the stack length (mm), σ is the ratio of L to D (L/D) and TVR is the torque/volume ratio.

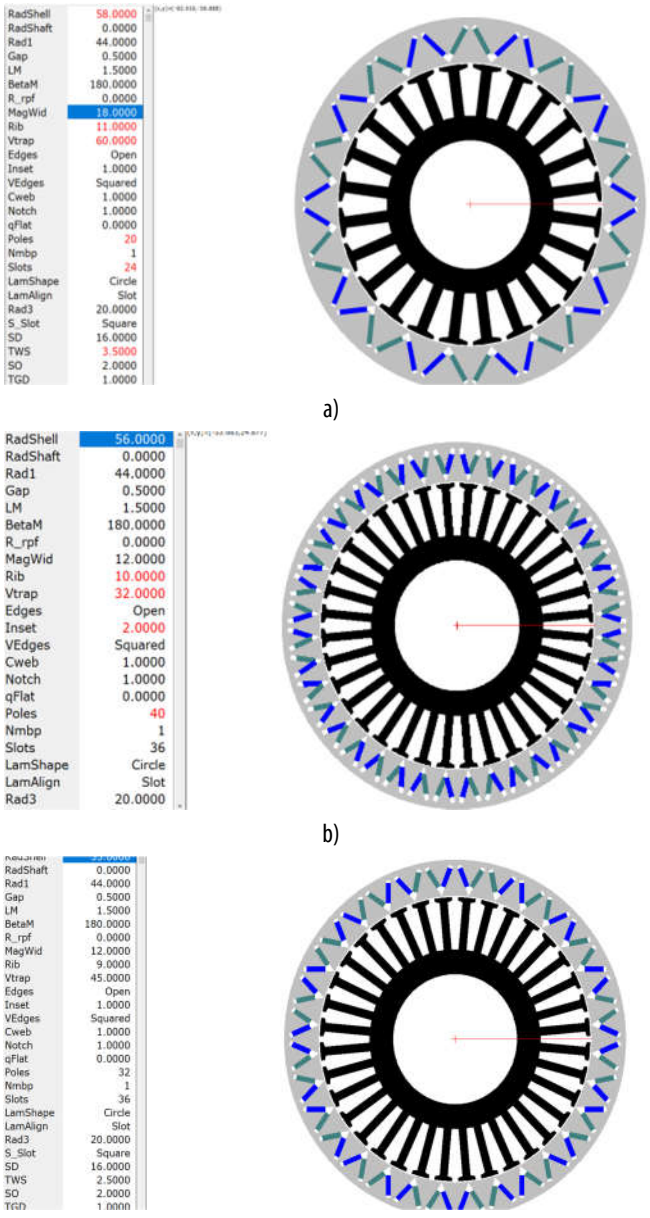


Figure 3. V shaped Magnet Outer Rotor
a) 24slots/20poles, b) 36slots/40poles, c) 36slots/32poles

The design interface is included design tools of geometry parameter in menu-bar and 2D drawing displayed in main design window. The 2D drawing of stator slots and rotor poles will be saved in a DXF file to import to the FEM simulation. The flux density and static torque results are auto saved in library files. The Matlab program is combined all data files and calculated torque and power as design sheets. The results will be stored in database in mat format. Main detail results of V shape IPM 36 slot/40 poles are shown Figure 3 and Figure 4.

Tshaft	43.2604	Nm	Pshaft	4530.2145	W	Eff	93.9495 %
WCu	228.8699	W	WFe	62.8845	W	WWF	0.0000 W
WTotal	291.7544	W	TempRise	5.0000	°C	Jrms	5.9382 A/mm²
wt_Cu	3.2824	kg	wt_Fe	2.0431	kg	wt_Mag	0.2988 kg
wt_Tot	5.6244	kg	wt_Shaft	0.0000	kg	wt_Frame	0.0321 kg
wt_FeS	0.9990	kg	wt_FeR	1.0441	kg	wt_RSS	1.4420 kg

Figure 4. Design sheet of V shape IPM 36S/40P

The shaft torque and power are respectively 43Nm and 4530W at the speed of 2000rpm not yet maximum speed but maximum efficiency of 93.94%. This design will compare with two other designs of 24S/20P and 36S/40P latter. There are three configurations of stator slots and rotor poles to obtain the high efficiency with 24 and 36 slots and 20/32/40 magnetic poles. In order to get the total performances compared with three models, the output power, torque and efficiency are calculated in Table 3.

Table 3. Geometry parameter of V shaper outer rotor

Parameters	Unit	24S20P	36S40P	36S32P
Average torque	Nm	39	43	40.016
Speed limit for zero torque	rpm	5449	7501	6508
Input Power	Watts	4,714.54	4,859.60	4,524.55
Output Power	Watts	4,369.00	4,530.60	4,182.70
Total Losses	Watts	345.54	329.00	341.85
System Efficiency	%	92.67	93.23	92.44
Shaft Torque	Nm	43.334	42.716	34.047
Total weight	kg	10.5	10.2	10.3
Power density	W/kg	416.10	444.18	406.09
Torque density	Nm/kg	4.03	4.29	3.89

From the obtained results in Table 3, the configurations of 36 slots/40 poles can get a maximum efficiency. The V shaped IPM motor with 36S/40P has been selected for the final design and detail performances that will be shown in Section 3.

3. SIMULATION RESULTS

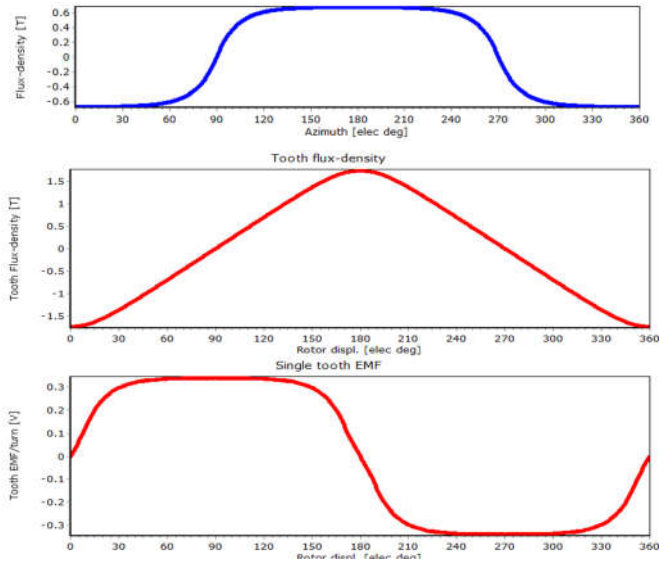


Figure 5. Flux density distribution of V shape outer rotor

In order to find the motor performance, the FEM is carried out to get flux density in air gap, tooth and tooth EMF/turn as shown in Figure 5.

The flux density in stator and rotor tooths are shown in Figure 5 with the maximum value of 1.6 Tesla. From the flux density distribution, it is observed that at no-load condition flux distribution is symmetrical. At the full load condition, the flux distribution is un-symmetrical because of the armature reaction. Since the energy conservation is processed through the air gap, the air gap flux distribution is necessary. The normal and tangential components of flux density and force density along the air gap periphery at full load condition is presented in Figure 6.

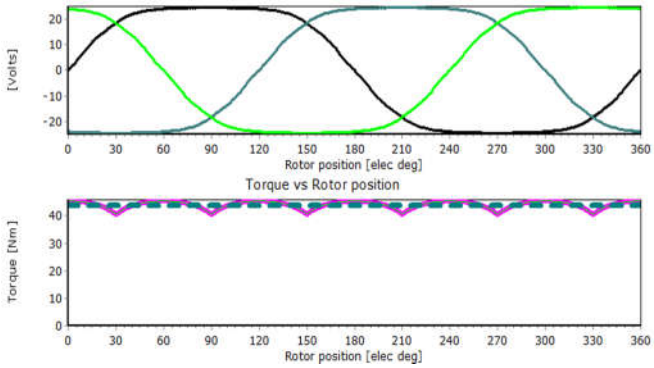
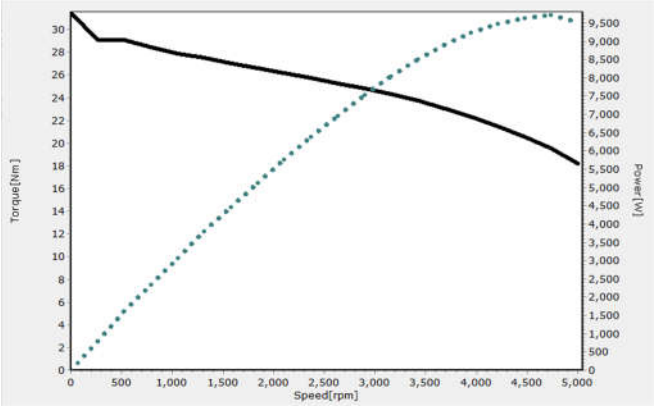
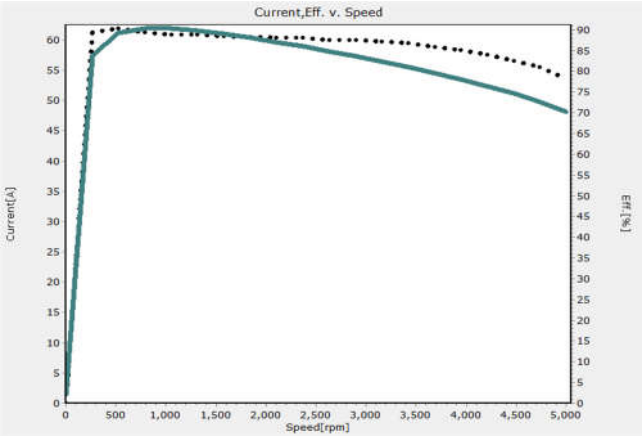


Figure 6. Back EMF and torque waveform of V shape outer rotor



a)



b)

Figure 7. Power and Torque (a) and DC link current and efficiency (b)

The output torque value of 45Nm is the peak torque requirement of 35Nm at the speed 2000rpm. Based on the motor specification, the power, torque, efficiency and DC link current have been validated with the speed from 0 to 5000rpm as shown in Figure 7. The input voltage is 72VDC from batteries, the DC link current is supplied to three phases being from 0 to 100A.

The peak power of V shape IPM motor can obtain 9500W at the speed 5000rpm. The torque value is 18N.m at the maximum speed and the current density is 6.5A/mm^2. The output power, torque and DC link current are important parameters for E-scooters in the normal operation and peak torque or peak power operations. The peak DC current from the battery is 100A, and maximum efficiency is about 90% being higher than the efficiency requirement.

4. CONCLUSION

This paper focuses on the V shaped magnet design of outer rotor of IPM with different stator/rotor configurations. The outer rotor of V shape permanent is the novel design for E-scooters. After three models of the V shaped outer rotor motor with 24slots/20 poles, 36 slots/32poles and 36slots/40poles, the design of 36slots/32poles has been selected with the highest efficiency and power density. By applying modern design programs of the analytical method and FEM, the power, torque and efficiency performances have been succesfully investigated and compared under the normal and peak torque operations. This paper can also contribute to electric motor bicyle developers and an outer rotor structure with V-shaped PM arrangement like IPM motors. Main advantages of this motor are to create the high torque and power constant in wide range speed because the high number of stator slot and rotor poles creates the small back EMF.

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THÔNG TIN TÁC GIẢ

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