DEMANGETIZATION RATIO ANALYIS OF PERMANENT MAGNETS FOR DOUBLE V AND DELTA ROTOR SHAPES

ĐÁNH GIÁ CÁC ĐẶC TÍNH KHỬ TỪ CỦA ĐỘNG CƠ NAM CHÂM VĨNH CỬU CỰC CHÌM KẾT CẤU ĐA LỚP V KÉP - DELTA

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ABSTRACT

The irreversible demagnetization due to short circuits the and overheat temperature effects have been influenced by arrangements of double V and ∇ layer of permanent magnets. This means that the magnetic flux density at the air gap and electromagnetic forces are also reduced. In addtion, the changes of V and Delta shape angles of the magnet arrangements will affect directly to sinusoidal waveforms of the electromagnetic forces due to harmonic components of the magnetic flux density at the air gap changing flowing to the rotor shape angle of V magnet layers. In this paper, interior permanent magnet motors with layered magnets of different shapes (V and Δ) are proposed to compute and simulate levels of the irreversible demagnetization of permanent magnets and the waveforms of electromagnetic force due to the overheat of permanent magnets. Two practical models with speeds of 4500 rpm and 16000rpm under different temperatures will be illustrated.

Keywords: *Interior permanent magnet motors, magnetic flux density, electromagnetic forces, Structure of VV and ∇shapes, finite Element Method.*

TÓM TẮT

Kết cấu đa lớp VV và ∇ nam châm vĩnh cửu đã ảnh hưởng đáng kể đến mức độ khử từ do sự cố ngắn mạch và hiệu ứng quá nhiệt. Điều này dẫn đến mật độ từ thông khe hở không khí và sức điện động cũng giảm theo. Hơn nữa, việc thay đổi theo góc hình dạng V và ∇ của sự sắp xếp nam châm vĩnh cửu, sẽ ảnh hưởng trực tiếp đến dạng sóng hình sin của sức điện động, do thành phần sóng hài của mật độ từ cảm tại khe hở không khí thay đổi theo dạng góc V của các lớp nam châm. Trong bài báo này, động cơ nam châm vĩnh cửu cực chìm kết cấu đa lớp V kép - Delta được nghiên cứu để đánh giá các đặc tính khử từ nam châm cửu và dạng sóng sức điện động do quá nhiệt của nam châm. Hai mô hình thực tế với tốc độ khác nhau (4500 vòng/phút và 16000 vòng/phút) với nhiệt độ khác nhau sẽ được minh hoạ và kiểm chứng.

Từ khóa: *Động cơ nam châm vĩnh cửu từ gắn chìm, mật độ từ cảm, sức điện động, kết cấu đa lớp VV và ∇, phương pháp phần tử hữu hạn.*

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1. INTRODUCTION

The irreversible demagnetization faults are considered in interior permanent magnet (IMP) motors because the residual flux densities of the IPM motor decrease as demagnetizing regions and increase owing to the overlap of inverse fluxes with big shorted- circuit currents in phase windings. The irreversible demagnetization is generally induced due to the increasing temperature of motors, the sudden three-phase short circuit and over-currents as well. The irreversible demagnetization of permanent magnets (PMs) is mainly caused by armature reactions appearing with a high requirement of starting torque. Hence, a thermal analysis of the irreversible demagnetization of electric motors has to consider, because this affects directly to electromagnetic performances and the lifetime of the motors.

The IPM motor with a maximum power of 120 kW with 48 stator slots and 8 poles using the Taguchi method with the optimization of the designed motor in terms of irreversible demagnetization has been recently proposed in [1]. The hybrid rotor concept with different magnet arrangements is also developed to reduce the temperature [2, 3], or an improved loss separation method is mentioned to reduce the loss and rotor temperature distribution applied to 800kW, 15000rpm in [3]. The V-shape combined with pole V-switch motor has been designed to improve the anti-demagnetization ability at the high temperature, and decrease the rare-earth PM consumption with the output torque remaining unchanged [4]. An IPM motor has been given to analyze the distribution of magnetic flux density at the air gap via the influence of the slotting and the concentration of the flux in the lower part of teeth [5-7].

In this paper, multi-layers multi-segments of IPM motors with the V-∇ shapes have been developed to compute and simulate electromagnetic performances taking the thermal and irreversible demagnetization problems into account, where each layer has an array of magnet segments and the number of magnet segments depends on magnet pole width and flux barriers. A matrix of multilayers and segments

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can be also investigated to see high irreversible diamagnetic levels and over-temperature problems. Based on the distribution of diamagnetic flux density and temperature, the parameters of IPM motor will be corrected/redesigned to avoid the permanent flux density reduction due to demagnetization in sort circuit problems as presented in [1-3]. The irreversible demagnetization due to short circuits is lead to reduce flux density of permanent magnets.

2. ANALYSIS OF VV AND ∇ ROTOR SHAPES

Many layers and shapes of magnet arrangement designs such as ∇-V-I-U topologies have been recently developed. Novel designs of them are always focussed on a combination of both ∇-V-I-U to obtain the total sinusoidal waveform of back electromagnetic force (EMF) and high torque and power density. This research is also based on those designs and developments of multi-magnet segments located in an array with each layer to reduce magnetic losses. In addition, this paper also allows identifying the magnet segments given the highest irreversible demagnetization levels due to the magnetic design, flux density and position.

Two magnet configurations with the typical VV and ∇ shapes are presented in Figure 1 [8]. Those topologies are popular for the automotive industry which are implemented by Wolong Motor. Many manet segments with standard sizes are easy to change the rating of magnet per slot or barrier width. The total volumes of the permanent magnets (i.e., 42 U) and original material cost are the same or change less than 5%. The N40UH magnetic properties are shown in Figure 2, where three operating points over the 180°C curve are given. It should be noted that the slope of the line crossing the B - H curve (load line) is calculated as:

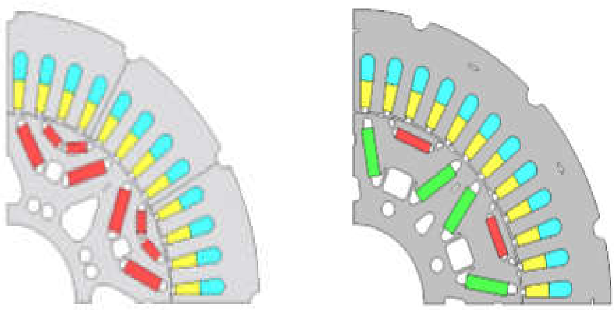


Figure 1. VV shape (left) and ∇ shape (right) topologies [8]

The non-linear demagnetization curves for magnets use magnet properties that are easily obtainable from magnet datasheets. It is useful to compute.

$$B = B_r + \mu_0 \mu_r H - E * e^{-k_1.(k_2+H)}, \quad (1)$$

$$k_2 = -\frac{\ln\left[(B_r + (\mu_r - 1).\mu_0.H_cJ).\frac{1}{E}\right]}{k_1} - H_cJ, \quad (2)$$

where: B_r is the redundant flux density, K_1 and K_2 are the non-linear demagnetization factors and H_C is the magnetic field in currier temperature.

From knee point of 150°C and 180°C demagnetization lines lie at -700kA/m and -500kA/m. If magnetic field strength drops below this value irreversible demagnetization would happen. For the magnet, permeability is equal to 1.05. The operating point most critical for demagnetization is the peak (S_2) knee point and maximum speed point.

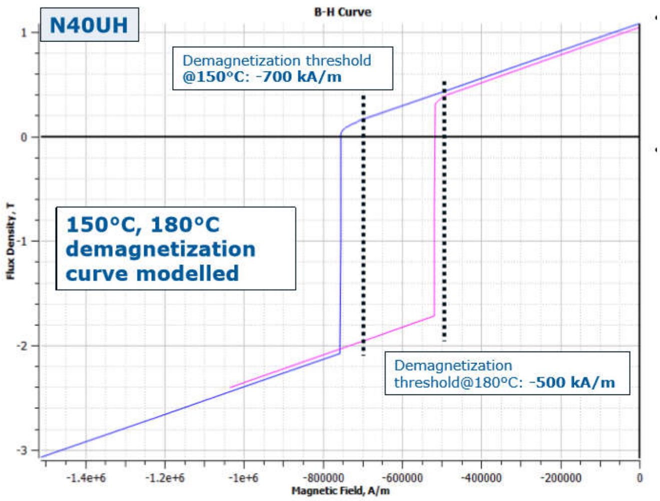


Figure 2. B-H curves of N40UH

3. DEMAGNETIZATION ANALYSIS

In order to model the effect that demagnetization will have on the torque produced by a machine. This will follow a similar procedure as for modeling the back EMF. However, a different drive cycle will be required. This drive cycle should have a 'normal operation' current to begin phase advance 45^0 electrical degrees, with the peak current of 700A, the demagnetization period and then a further period of normal operation.

In this study, the speed of normal operation is 4500rpm, and the effect of demagnetization on the torque-producing capabilities of the motor is implemented by in a short time. The peak current of the short circuit is to 1616Apk for the VV shape as in Figure 3 and 1544Apk in -40^{0}C for the ∇ shape as in Figure 4.

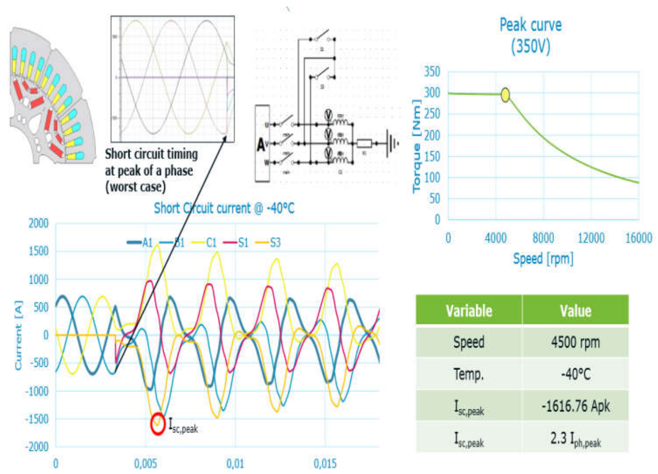
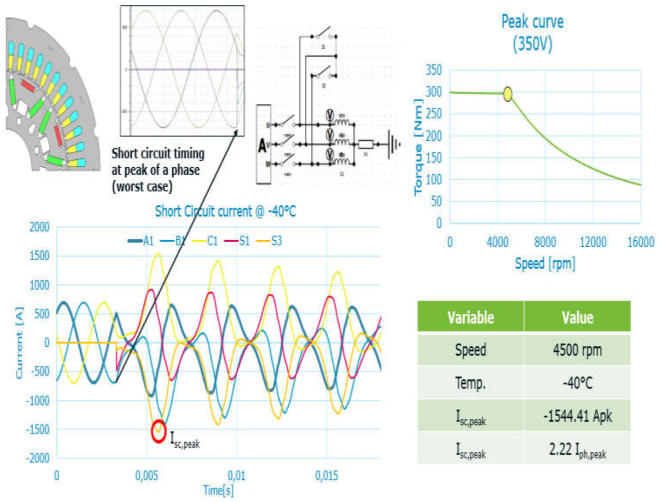


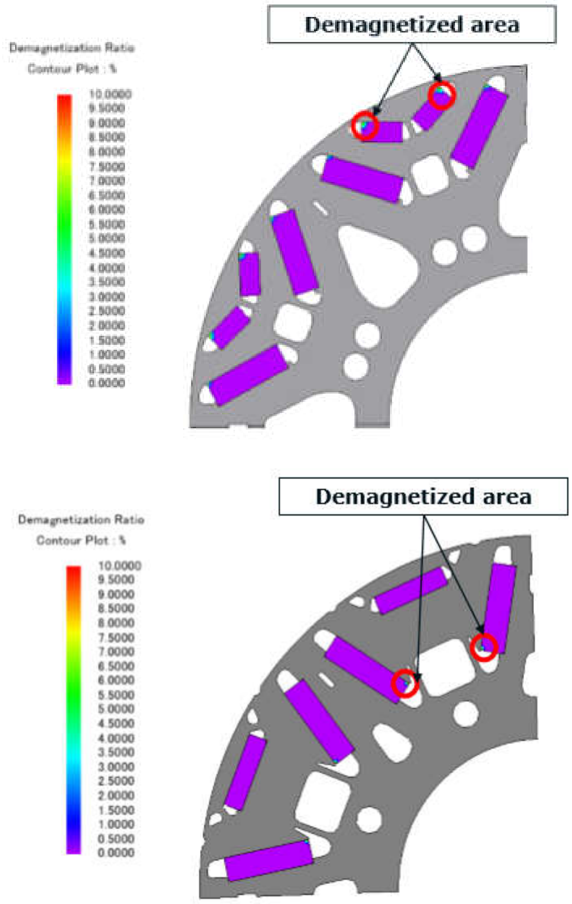
Figure 3. Flux short circuit current of VV shape



Variable	Value
Speed	4500 rpm
Temp.	-40°C
$I_{sc,peak}$	-1544.41 Apk
$I_{sc,peak}$	2.22 $I_{ph,peak}$

Figure 4. Flux short circuit current of VV shape

In order to investigate the irreversible diamagnetic values of two IPM models, the flux density of the permanent magnet is affected by three phase currents of 1616Apk and 1544Apk simulated by the finite element method when three phases were short circuit at base speed of 4500rpm. Demagnetization results of different designs (VV and ∇) at the speeds of 4500rpm and 16000rpm are expressed in Figure 4. The demagnetization ratio of the area of the magnet is 3% in VV design and 2.5% in ∇ design. It shows that delta design is better than double V design in terms of demagnetization level.



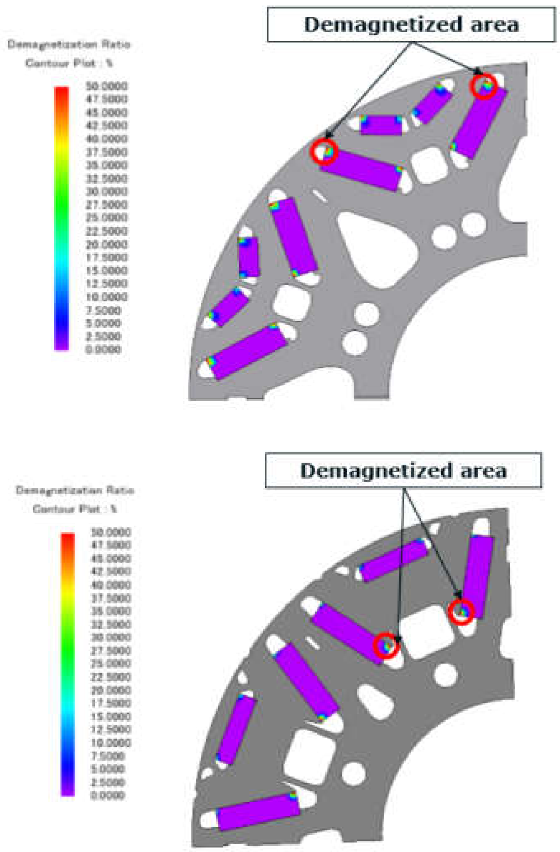


Figure 5. Demagnetization ratio of VV and ∇ design: VV design @ 4500rpm 160°C (top left); ∇ design@ 4500rpm 160°C (top right); VV design @ 16000rpm 160°C (bottom left); ∇ design@ 16000rpm 160°C (bottom right)

4. CONCLUSION

This paper has investigated and compared the irreversible demagnetization of VV and ∇ magnet arrangement for electric vehicle applications. The demagnetization ratio of the two models has been sucessfully implemented at the speeds of 4500rpm and 16000rpm under different temperatures. The significant contribution of this work is to point out the VV design of magnet arrangements which has a higher risky of the demagnetization level. The investigation has been also found that the best design to achieve the minimum temperature rise and irreversible demagnetization. This has been given out a novel magnet arrangement for improving demagnetization and thermal distribution of IPM motors for electric vehicles.

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