Analysis and Design of SPM Type Variable Flux Memory Motor Considering Demagnetization Characteristic of Permanent Magnet

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Background

Permanent magnet(PM) Synchronous motor have a wide variety of industrial applications due to high efficiency and torque density. But the flux weakening(FW) control method is applied to increases operation area of PM synchronous motor. To achieve wide speed operation, a new class of PM motor has been proposed, of which the PM magnetization state can be tuned by applying d-axis current flux. This new class of PM motor is a variable flux memory motor(VFMM). In general, VFMM use ferrite PM, because it is easy to control the magnet field.

Objectives

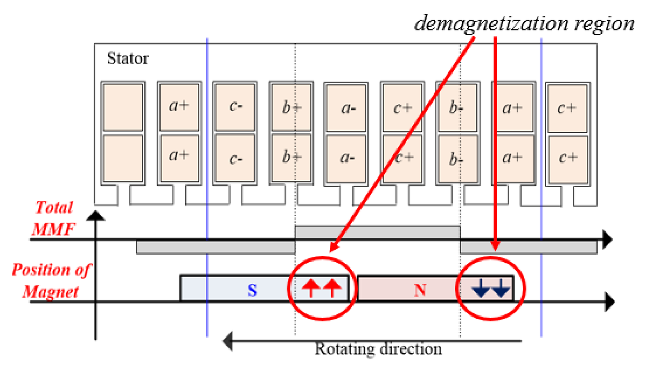
- Because of the low coercive force, irreversible demagnetization can be easily take placed in PM of VFMM by the armature reaction field.
- The powerful and easy method which prevent the irreversible demagnetization is changing the material property of PM. But, this method charge inefficient cost.
- This paper propose the method to prevent irreversible demagnetization by changing the rotor geometry of VFMM.

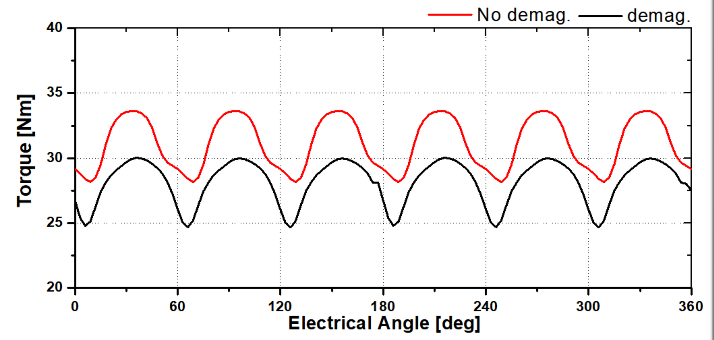
Conclusion

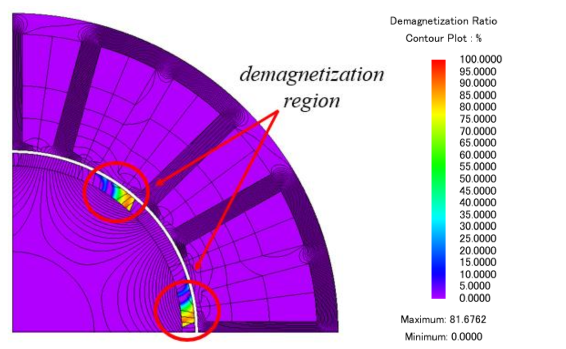
- To design the VFMM which drive wide range, demagnetization of PM is very important factor.
- In this paper, to reduce the demagnetization in load condition caused by armature winding, 3 method are proposed.
- Changing material method reduce demagnetization ratio in load condition(D.R.L) from 63% to 0% using high grad magnet.
- Inserting flux barrier method is effective to increase demagnetization ratio when we put the d-axis current pulse to reduce the magnetic field intensity of PM. But it is hard to prevent the increasing D.R.L.
- To overcome the disadvantage of method 2, we adopt the magnetic reluctance concept and permeance coefficient which is connected to the effective magnet thickness of the demagnetization region
- Increasing magnet thickness method reduce D.R.L value from 63% to 7.3%. But to get the wide range operation region of VFMM, we choose the x=4mm , because of the higher and bigger D.R.C and torque then method 1.

Methods

Demagnetization

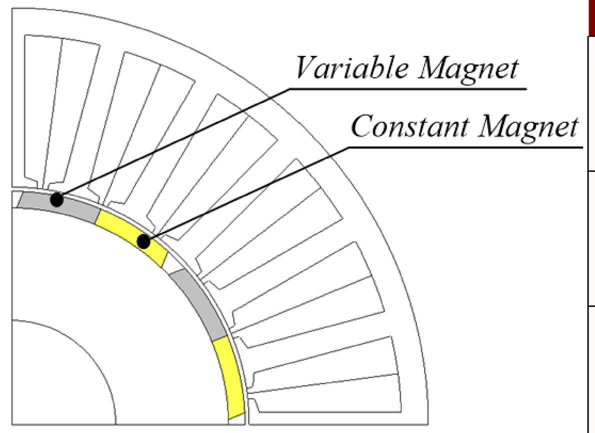






- **load condition:** Irreversible demagnetization of PM can be caused by armature winding.
- **Demagnetization:** Because of the demagnetization of PM, average torque and power density are decreased.

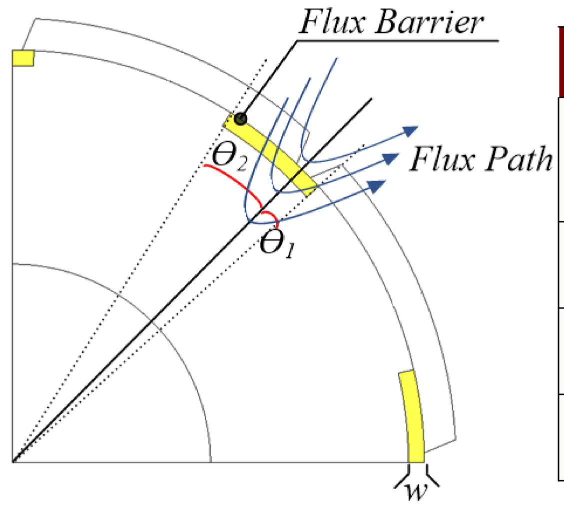
Method 1 - Changing the Magnet Material



Component		Amplitude
7-Grade (variable Magnet)	B_r (T)	0.44
	H_c (A/m)	228000
9-Grade (Constant Magnet)	B_r (T)	0.44
	H_c (A/m)	331145
Nd (Constant Magnet)	B_r (T)	1.075
	H_c (A/m)	825067

In this part, to prevent the demagnetization of magnet, demagnetization regions are replaced to constant magnet such as 9-Grade or Nd magnet.
This method is powerful and easy to reduce demagnetization phenomenon, and increase average torque and power density.

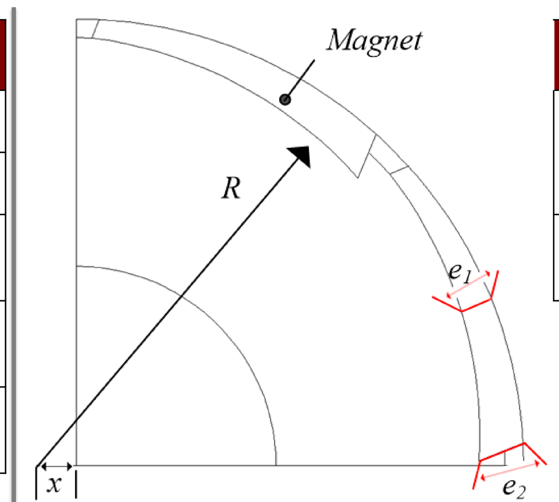
Method 2 - Inserting Flux Barrier



Component		Amplitude
Magnet (7-Grad)	B_r (T)	0.44
	H_c (A/m)	228000
θ_1		1, 2, 3, 4, 5
θ_2		11, 12, 13, 14, 15
w		1, 2, 3, 4, 5

In this part, effective air-gap length of Flux which make demagnetization of PM increase, because flux path occur in low magnetic reluctance value.
Therefore, exact width and thickness of flux barrier are important factor to prevent demagnetization of PM.

Method 3 - Increasing Magnet thickness



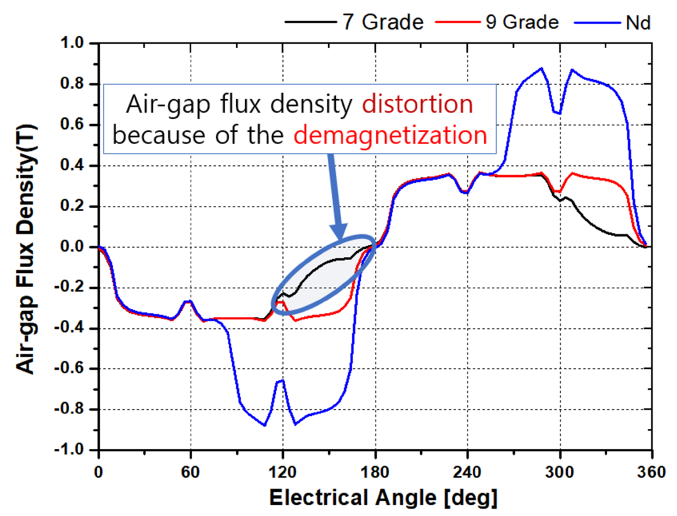
Component		Amplitude
Magnet (7-Grad)	B_r (T)	0.44
	H_c (A/m)	228000
x		1, 2, 3, 4, 5

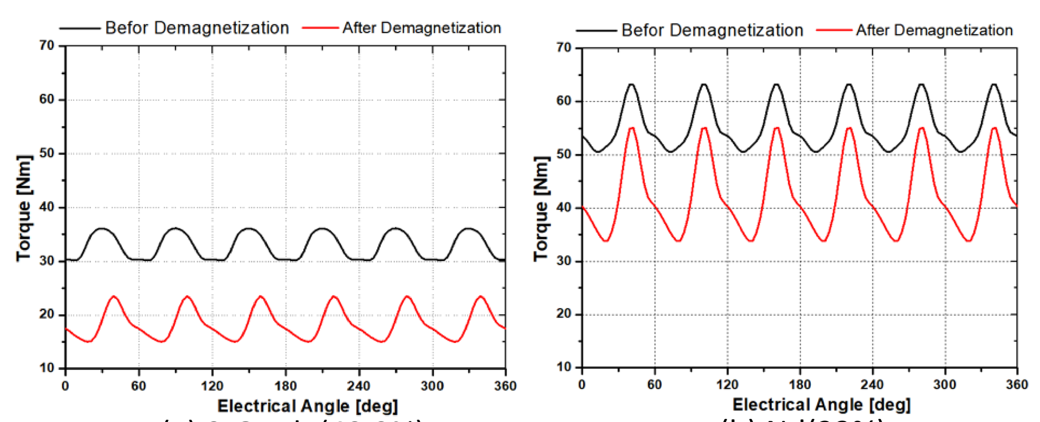
$$\Re_m = \frac{l}{\mu A} \qquad l = (e_1 + e_2)/2$$

In this part, effective magnet length to make high the permeance coefficient(PC) value increase, because magnet operating point rise when the PC value increase. Therefore, effective magnet length is important factor to reduce the demagnetization region.

Results

Characteristics and result of Method 1





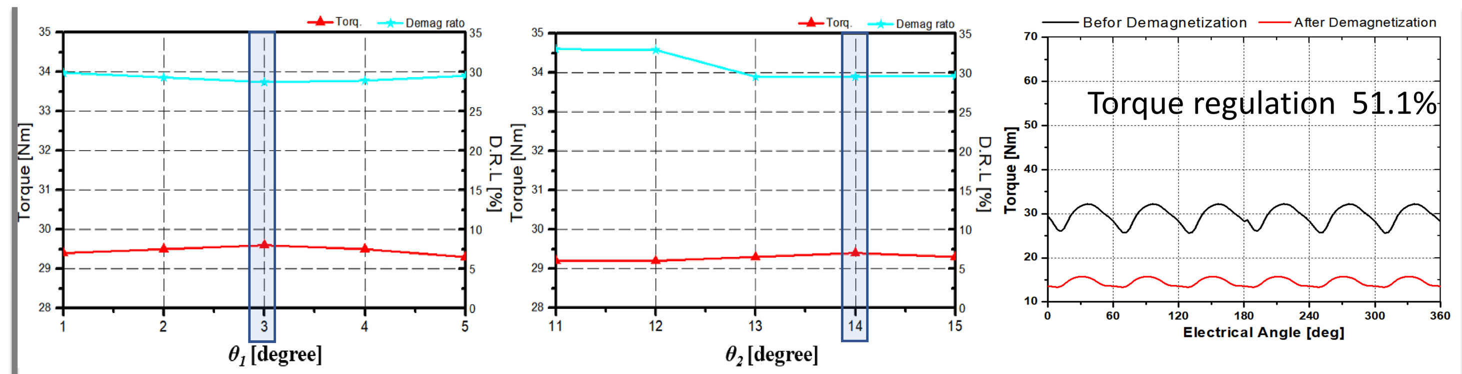
(a) 9-Grade(43.9%) (b) Nd(23%)

Torque regulation

Component		Amplitude
7-Grade (variable Magnet)	*Torque (Nm)*	28.1
	D.R.L (%)	63.5
	D.R.C (%)	87.6
9-Grade (Constant Magnet)	*Torque (Nm)*	32.8
	D.R.L (%)	2.8
	D.R.C (%)	91.0
Nd (Constant Magnet)	*Torque (Nm)*	55.3
	D.R.L (%)	0
	D.R.C (%)	91.4

- Changing magnet material method are adapted to demagnetization region.
- This method is powerful and strong to prevent the irreversible demagnetization, in load condition
- Through this method, D.R.L decrease.
- But, it charge inefficient cost, because of the using high grade PM.

Characteristics and result of Method 2

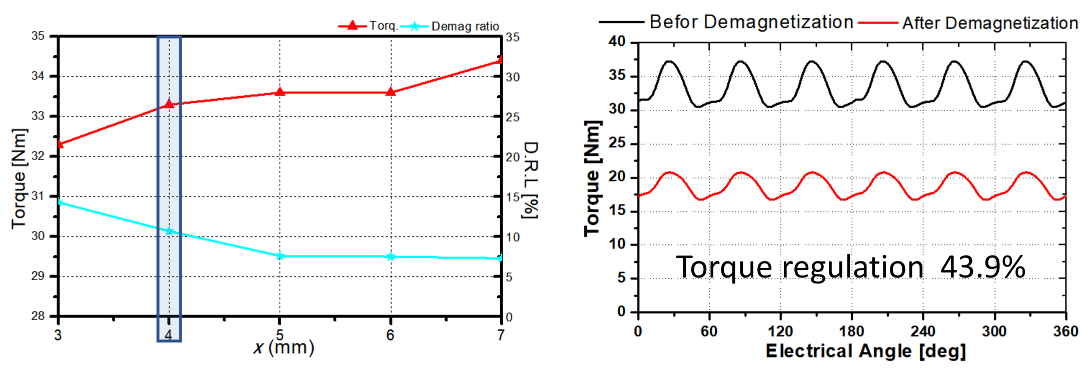


Component	Amplitude				
w (mm)	1	2	3	4	5
Torque (Nm)	29.6	30.0	30.2	30.3	30.4
D.R.L (%)	28.7	25.6	24.3	23.6	23.1
D.R.C (%)	57.7	55.2	53.9	53.3	52.2

- Inserting the flux barrier method has excellent performance about the high D.R.C ratio which is important factor of VFMM.
- Therefore exact width and thickness of the flux barrier is necessary to increase the performance of this method
- In this part, θ_1 , θ_2 and w are 3 and 14degree and 1mm, because of the high torque and low D.R.L.
- Through this method, we can achieve torque regulation 51.1% .

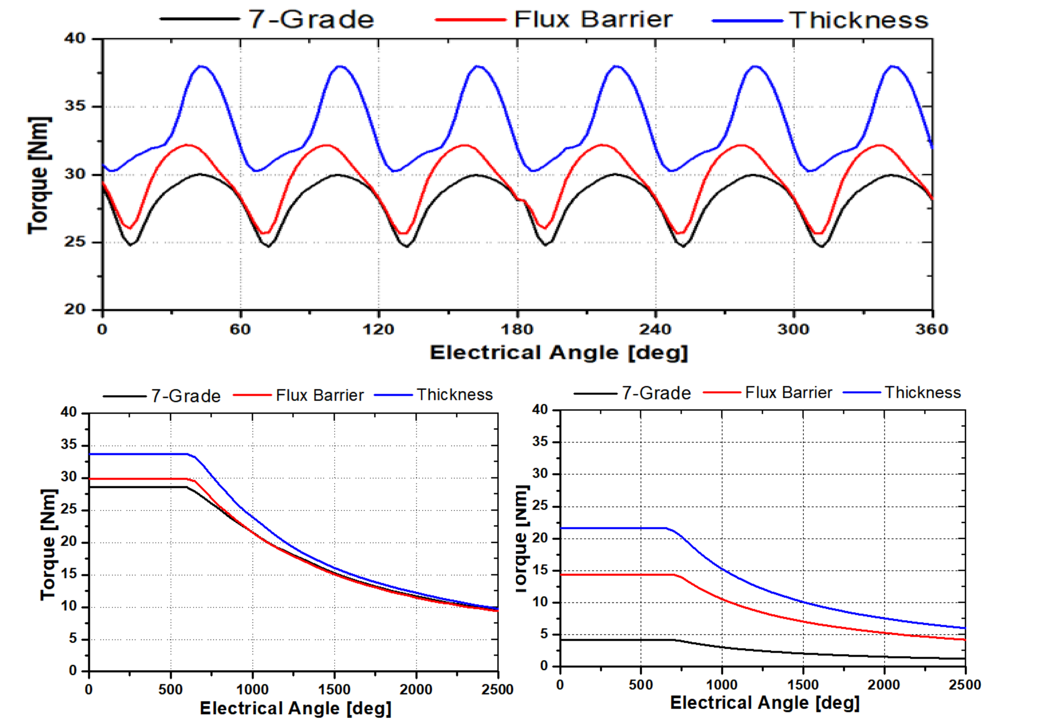
Characteristics and result of Method 3

Component	Amplitude				
x (mm)	3	4	5	6	7
l (mm)	4.6	4.8	5.0	5.1	5.5
Magnet Area	153.3 (mm^2)				
Torque (Nm)	32.3	33.3	33.6	33.6	34.4
D.R.C (%)	56	49.2	41.5	40.7	28.3



- The effective magnet thickness is connected to magnetic reluctance value and permeance coefficient.
- Therefore, D.R.L is decreased, and D.R.C and torque are increased by increasing the effective magnet thickness
- Through this method, we can achieve torque regulation 43.9%

Conclusion



- Changing material method is effective to reduce demagnetization in load condition.
- Inserting flux barrier method is effective to reduce d-axis demagnetization current
- Changing the effective magnet thickness method is effective to demagnetization in load condition as method1.