Numerical Analysis of Variable Flux Memory Motor Considering Characteristics of PM Load-line

Jun-Young Song[1], Wonseok Han[1], Yong-Jae Kim[2], Sang-Yong Jung[1]

1. School of Electronic and Electrical Engineering, SungKyunKwan University, Suwon, 16419, Republic of Korea
2. Department of Electrical Engineering, Chosun University, Gwngju, 61452, Republic of Korea

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Abstract

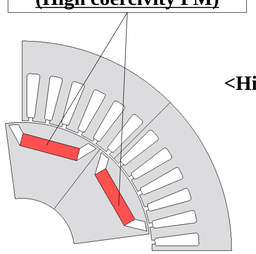
In this paper, we investigated permanent magnet (PM) load-lines to identify and compare the magnetization characteristics of two general types of variable flux memory motors (VFMMs). When large armature current is applied to VFMM, the main flux paths become highly saturated, which cause distortion of PM load-lines. Hence, the PM load-lines are derived via nonlinear finite element analysis (FEA) to consider magnetic saturation phenomena in this paper. Under different armature d-axis current conditions, the movements of PM load-lines of analysis models are studied, and finally we identify which topologies are more suitable for VFMM.

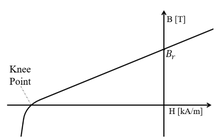
Introduction

In general, high-coercivity PM is used for conventional PMSM to prevent demagnetization. It is impossible to control PM flux directly, so that operation range is restricted.

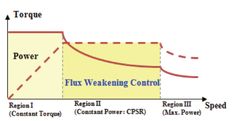
⇒ To obtain high efficiency over wide-speed operation region, variable flux memory motor (VFMM) has been proposed, of which the PM magnetization strength can be adjusted by applying d-axis current pulses.

Constant magnetized PM (High coercivity PM)





<High coercivity PM for conventional PMSM>

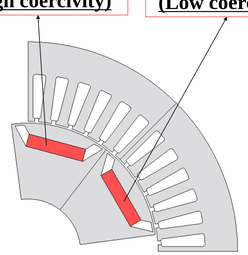


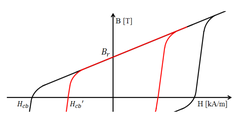
<Torque-speed curve of PMSM>

Conventional PMSM

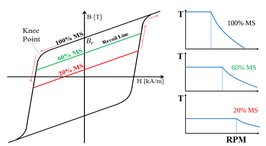
Constant magnetized PM (High coercivity)

Variable magnetized PM (Low coercivity)





<High coercivity and low coercivity PMs for VFMM>



<Variable torque-speed curve>

Variable Flux Memory Motor

Assumptions

• There is no significant difference in the values of magnetic flux density (B) and magnetic field strength (H) of elements inside the PM under no-load and d-axis input current conditions. ⇒ **For one PM, B and H are dealt with average values.**

• When armature current is applied to the motor, the PM operating point dynamically varies following minor hysteresis loops. However, the loops are thin and have slope essentially equal to that of demagnetization characteristic. ⇒ **Piecewise-linear hysteresis model of PM is employed for derivation of PM load-line.**

PM operating point and load-line

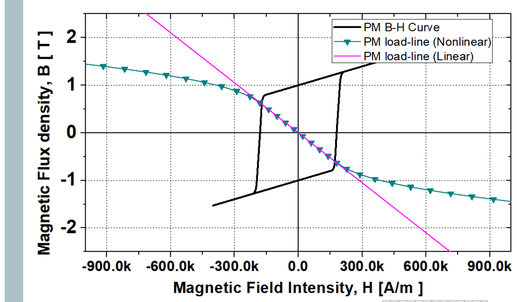
- **PM operating point** can be equivalently expressed as a point (H, B) on the PM B-H characteristic curve as following equations.

$$H = \sum_n [H_{x,n} \times \cos\theta + H_{y,n} \times \sin\theta] / n \qquad B = \sum_n [B_{x,n} \times \cos\theta + B_{y,n} \times \sin\theta] / n$$

- **PM load-line** can be inversely derived by connecting the calculated PM operating points in accordance with different values of remanence flux density, which have regular interval.

Analysis results

Linear analysis VS Nonlinear analysis



■ Linear analysis

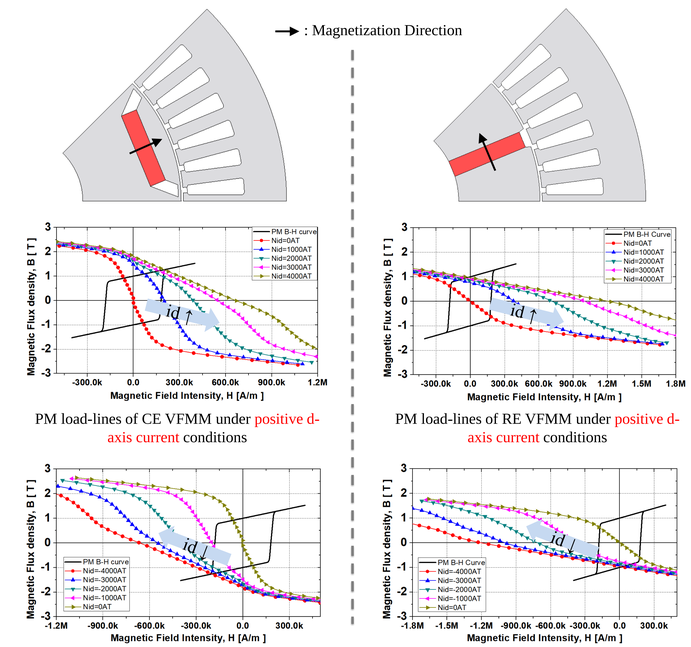
: linear iron core material ($\mu_r = 7000$) is employed for analysis of PM load-line.

■ Nonlinear analysis

: B-H characteristic data of iron core based FEA.

⇒ As magnetic flux density increases, the difference between linear and nonlinear analysis increases, which is mainly caused by magnetic saturation.

Circumferentially embedded (CE) type VFMM | **Radially embedded (RE) type VFMM**



PM load-lines of CE VFMM under positive d-axis current conditions

PM load-lines of RE VFMM under positive d-axis current conditions

PM load-lines of CE VFMM under negative d-axis current conditions

PM load-lines of RE VFMM under negative d-axis current conditions

Conclusion

This paper presents characteristics of PM load-line of VFMMs which are CE and RE types PM motors. Generally, it is known that if d-axis current is applied to VFMM, the PM load-line is shifted the magnetic flux density-axis horizontally on the B-H characteristic curve. However, the FEA results showed that it does not move horizontally but in askew direction, which is mainly caused by magnetic saturation. In particular, RE VFMM is significantly influenced by this phenomenon compared to CE VFMM.