A Study of End-effect on Demagnetization in Surface Permanent Magnet Motor without Overhang

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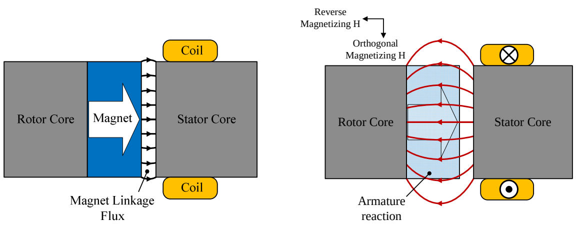
In order to compensate the low performance of ferrite magnet, surface permanent magnet mounted (SPM) motor has considerably thicker magnet than air-gap length, thus end effect, which is determined by the ratio between magnetic air-gap and stack length, is negligible. As a result, 2-D finite element analysis (FEA), which is not possible to consider end effect, is generally used to ensure analysis accuracy in SPM motor without overhang structure. However, unlike other analysis such as back-EMF, demagnetization analysis of SPM cannot be ensured by 2-D FEA, because end effect is no longer ignored. In the demagnetization, magnetic air gap, which determines the level of end effect, is increased by the fact that the permeability of magnetized magnet is almost similar to vacuum, thus only 3-D FEA is used to ensure analysis accuracy. We has found this phenomenon by comparison between the results of 2-D and 3-D FEA, and finally we are plan to validate the simulation result by experiment test.

***Index Terms*— Demagnetization, Surface Permanent Magnet Motor, End-effect, Armature reaction**

I. Introduction

Permanent Magnet (PM) machines have increasingly received popularity in the domestic and office products and industrial applications benefiting from higher efficiency and torque density over the conventional electrically excited machines [1-3]. In particular, Surface PM mounted (SPM) machines having many advantages such as low leakage flux, high cost competitiveness, and high mass productivity. However, demagnetization, which is produced as a result of the interaction between PM and armature current, cause reducing motor performance and undesirable noise, thus has to be considered in the design of PM motors[4]-[6].

In general, SPM motor has a very small air-gap compared with stack length, thus end effect, which is determined by the ratio between magnetic air-gap and motor stack length, is negligible. As a result, 2-D FEA, which is not possible to consider end effect, is used to ensure analysis accuracy in SPM motor without overhang structure. However, unlike other analysis, demagnetization analysis of SPM motor cannot be ensured accuracy by 2-D FEA, because end effect is not possible to be ignored in the demagnetization situation. In the demagnetization unlike other situation, magnetic air gap is increased to the summation of mechanical air gap and magnet thickness by the fact that the permeability of magnetized magnet is almost similar to vacuum. In conclusion, in order to analyze the demagnetization of SPM, 3-D FEA, which is possible to consider end effect, have to be used to ensure analysis accuracy. Figure 1 shows a conceptual view of the foregoing description. Figure 1(a) shows the reason that 2-D FEA is acceptable to consider the performance prediction of SPM motor. There is a little fringing, because air-gap is considerably small compared with stack length. In contrast, demagnetizing flux, which is produced by armature current, has considerably fringing effect as shown in Figure 1(b), because the permeability of magnetized magnet is almost similar to vacuum.

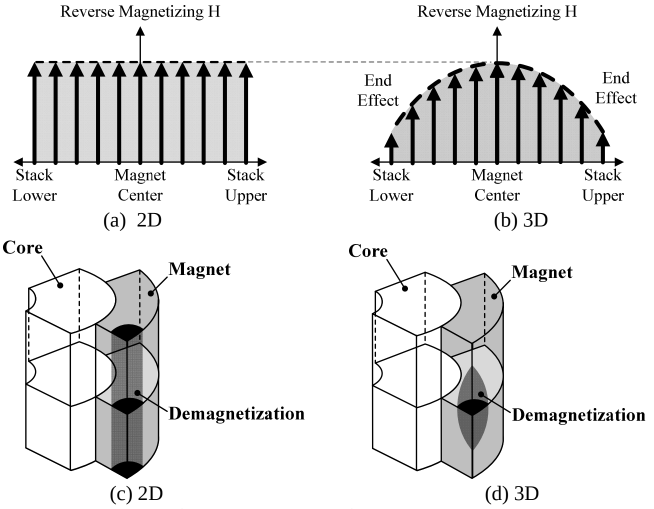


(a) Magnetic flux from PM (b) Magnetic flux from armature current
Fig. 1 Conceptual view for the reason of exiting end effect in demagnetization

II. Demagnetizing Field Due to End Effect

All motor in the world do not have infinite stack length, thus it cannot but have end effect based on both fringing and axial leakage flux. However, for the analysis of a motor where the stack length is considerably larger compared to the air-gap, 2-D simulation such as 2-D FEA is used to ensure acceptable analysis error. SPM motor, which has sufficient stack length compared with air-gap, is generally used 2-D FEA to predict the performance such as back-EMF, output torque, and efficiency.

The result of 2-D demagnetization analysis is different with 3-D result, because of end effect. Figure 2(a) and 2(b) show the difference of demagnetizing field distribution due to end effect. Demagnetizing field in the middle of stack is same with between 2-D and 3-D, because of symmetry; however, 3-D field always is smaller than 2-D field in other region except middle. Figure 2(c) shows demagnetization region in 2-D analysis, and the demagnetization region in 3-D analysis is shown in Figure 2(d). The region of demagnetization in 2-D analysis is always bigger than 3-D analysis, because there is no end effect in 2-D. Even though after starting of demagnetization, analysis error between 2-D and 3-D FEA is not zero, but the current at starting of demagnetization is identical.



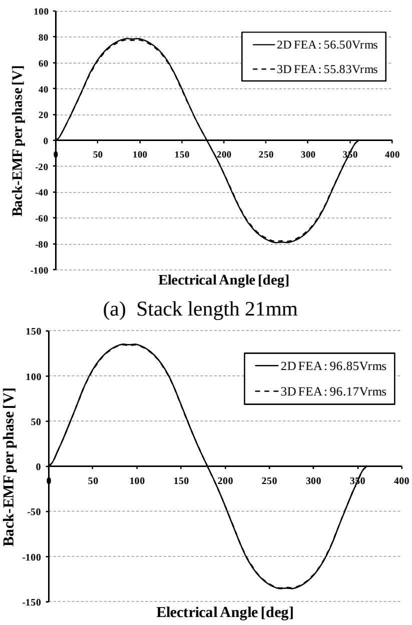
(a) 2D (b) 3D

(c) 2D (d) 3D

Fig. 2. Comparison of the demagnetizing field distribution between 2D and 3D simulation. (a) Demagnetizing field distribution according to stack length in 2D; (b) Demagnetizing field distribution according to stack length in 3D; (c) Demagnetizing region in 2D; (d) Demagnetizing region in 3D

III. Analysis results and Discussion

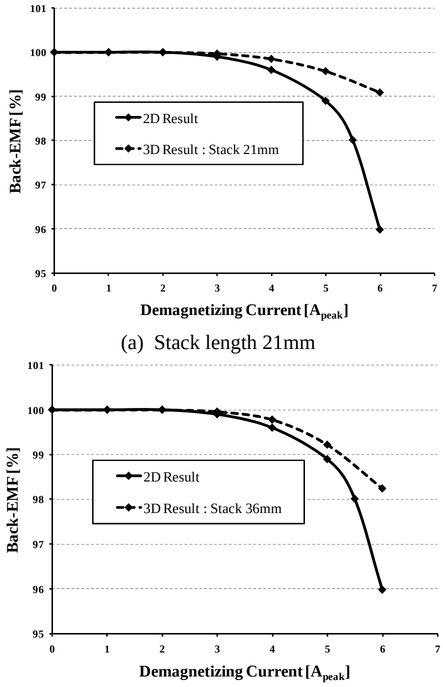
Figure 3(a) shows the comparison of back-EMF between 2-D and 3-D analysis results of stack 21mm model, and Figure 3(b) is results of stack 36mm model. There is very small analysis error. In the stack 21mm, analysis error of between 2-D and 3-D is 1.38%, and stack 36mm has only 0.7% error, however, demagnetizing analysis results as shown in Figure 4(a), (b) represent considerably analysis error between 2-D and 3-D, and especially as the current increases, analysis error increases. In addition, less the stack length is more analysis error, because of increasing of end effect. For example, in the 6A current, analysis error between 2-D and 3-D FEA are 3.1%p at 21mm stack and 2.3% at 36mm stack.



(a) Stack length 21mm

(b) Stack length 36mm

Fig. 3. Comparison of no-load EMF between 2D and 3D simulation in SPM motor, which has air gap 0.4mm, stack length 36mm, magnet thickness 6mm.



(a) Stack length 21mm

(b) Stack length 36mm

Fig. 4. Comparison of demagnetization simulation results between 2D and 3D.

IV. Conclusion

In generally, 2-D FEA is used to ensure analysis accuracy in the performance simulation of SPM motor without overhang structure, however, demagnetization is only possible to be predicted accurate by 3-D FEA, because demagnetizing field produced by armature current, which is unlike with magnetic field from magnet, has considerably fringing phenomenon. In this paper, this fact, which has been ignored in conventional literatures, was found by the comparison between 2-D and 3-D FEA, and we analyze the reason of this phenomenon. In the same computer, calculation time of 2-D FEA was only a few minutes, while 3-D FEA analysis time was more than 4 hours.

References

[1] Z. Q. Zhu and D. Howe, "Electrical machines and drives for electric, hybrid, and fuel cell vehicles," Proc. Of IEEE, vol. 95, no. 5, pp. 746-765, 2007.

[2] Z. Q. Zhu and C. C. Chan, "Electrical machine topologies and technologies for electric, hybrid, and fuel cell vehicles," in IEEE Vehicle Power and Propulsion Conf., 2008, pp.1-6.

[3] A. M. El-Refaie, "Fractional-slot concentrated-windings synchronous permanent magnet machines: opportunities and challenges," IEEE Trans. Ind. Electron., vol. 57, no. 1, pp. 107-121, 2010.

[4] J. R. Riba, J. A. Rosero, A. Garcia, and L. Romeral, "Detection of demagnetization faults in permanent-magnet synchronous motors under nonstationary conditions," IEEE Trans. Magn., vol. 45, no. 7, pp. 2961-2969, Jul. 2009.

[5] K. C. Kim, S. B. Lim, D. H. Koo, and J. Lee, "The shape optimization of permanent magnet for permanent magnet synchronous motor considering partial demagnetization," IEEE Trans. Magn., vol. 42, no. 10, pp. 3485-3487, Oct. 2006.

[6] A. Garica Espinosa, J. A. Rosero, J. Cusido, L. Romeral, and J. A. "Ortega, "Fault detection by means of Hilbert-huang transform of the stator current in a PMSM with demagnetization," IEEE Trans. Energy Convers., vol. 25, no. 2, pp. 312-318, Jun. 2010.