Dynamic Modeling of the Demagnetization in Halbach Array Permanent Magnet Machine

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***Abstract*—This paper presents the modeling of the construction procedure of a halbach array electrical machine and the corresponding partial demagnetization. Comparison between a static simulation with all magnets at their final positions and dynamic one where one of the magnets is brought to its final position from an initial one shows that the static solution overestimates the demagnetization phenomenon and lead to erroneous results. Such an error is due to the fact that the pre-positioning demagnetization is not accounted for in the static case.**

***Index Terms*—Permanent magnet machines, permanent magnets, demagnetization.**

I. Introduction

Permanent magnets are largely used in electrical machines, especially in generators for wind energy. However, permanent magnets are prone to partial or full demagnetization for many reasons. Several publications described these reasons and investigated them mainly under faulty operation of the machine like short-circuit [1], [2], overheating of the machine [2] and overload [4]. Modeling issues related to considering the demagnetization in operating electrical machines have also been presented in [5]-[7]. However, the possible demagnetization of the magnet and its description during the manufacturing process has received very little attention.

In the design process of permanent magnet machines, it is important to raise the magnetic flux density in the air gap of the machine as high as possible. This is necessary to achieve high efficiency and high power density [4]. Different constructions are used to achieve this goal through magnet shapes and positioning as well as layering, e.g., to form a Halbach array [2], [4]. However, the interaction between the different magnets adds to the stress on the magnets and increases the risk of demagnetization even before the machine is operating. In this paper we describe and model a situation, where low-cost magnets, used in Halbach array to achieve higher magnetic flux density in the air gap, are subjected to high enough demagnetizing filed and experience partial demagnetization during the assembly process.

II. Machine Design

The machine under investigation is a low-speed large-diameter slotless permanent magnet generator. To achieve high enough flux density in the air and save in the magnet cost as well as to simplify the manufacturing process, ferrite magnets of the same standard shape with dimensions 100x150x25 mm are used to assemble the Halbach array in the rotor as described in [4], [8]-[10].

First the main magnet is assembled from four magnets mounted on top of each other, after which the side magnets are added one at the time. An illustration of the investigated model is shown in Fig. 1. When the so constructed assembly was analyzed with a finite element model, no demagnetization could be seen. However, measurements on the assembled machine showed that partial demagnetization of the side magnets has occurred during the assembly process.

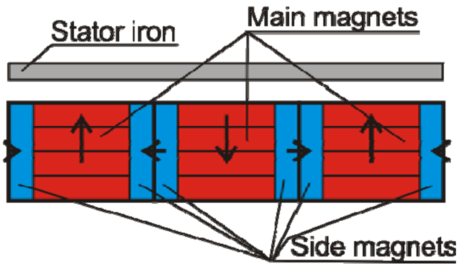

Fig. 1. Illustration of the constructed Halbach array test model. The coils of the stator are represented as air as they do not participate under no-load.

III. Method and Analyses

Finite elements analysis is the main tool used in this work. A parameterized model has been constructed in the commercial software FEMM, where one of the side magnet blocks was divided into 64 smaller domains. Two different situations were investigated. First, one side magnet was placed next to the main magnet and the resulting field distribution was computed with a static approach. The results from this computation are shown in Fig. 2. From this figure it can be seen that 12 domains out of the 64 are fully demagnetized and the domains next to them are partially demagnetized.

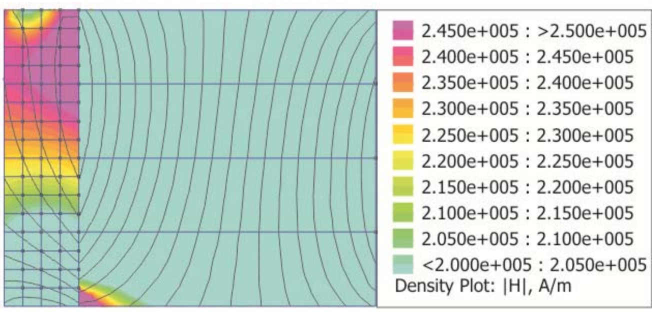

Fig. 2. Computed distribution of the magnetic field strength for the case where the side magnet is positioned next to the main magnet.

The second analysis aimed at finding when the demagnetization started. This was achieved by simulating the process of bringing the side magnet near the main magnet. The side magnet was moved to its final position next to the main magnet from an initial position far enough from this latter one. The motion was made in steps of 5 mm after which new computation was carried out. A modified demagnetization curve was applied to the demagnetized part of the magnet whenever such a phenomenon occurred. A set of those curves is shown in Fig. 4, where the main demagnetization curve as well as the new curves can be seen. Results of this second modeling procedure are shown in Fig. 3. It can be seen that the demagnetization of the side magnet starts when the distance from the main magnet was 20 mm. When the side magnet is brought closer to the main one, the demagnetization reaches more and more domains although the magnetization curves of the previously demagnetized ones where updated. The curves shown in Fig. 4 are numbered according to Fig. 3.

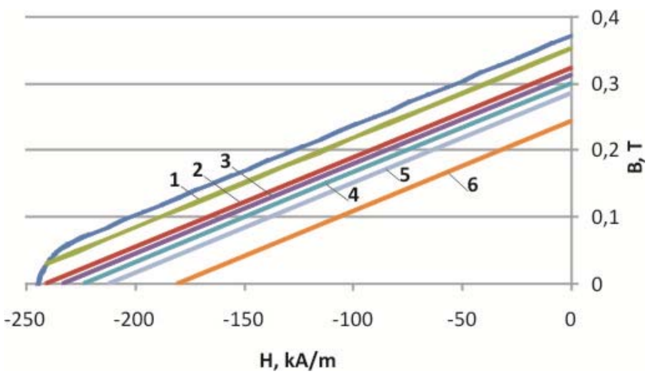

Fig. 4. Magnetization as a function of applied field. The curves are the ones used for updating after demagnetization. The numbering correspond Fig. 3.

A comparison of the filed distribution from Fig. 2 and Fig. 3. at the final position shows clear differences in the field distribution. It can be seen from Fig. 2 that a large amount of demagnetization occurs in the side magnet and some parts of it are fully demagnetized. Fig. 3 shows that as the permanent magnet starts to demagnetize at a certain distance from the main magnet, and the magnetization curves are updated, the final demagnetization is not as serious as the one computed with the static approach, where the side magnet is already at its final position. As a conclusion, the proposed dynamic computation of demagnetizations at the construction process is necessary to achieve accurate knowledge about the amount of demagnetized material and its location. A single static computation at the final position of the magnet overestimates this phenomenon and leads to erroneous results.

REFERENCES

[1] T. Hosoi, H. Watanabe, K. Shima, T. Fukami, R. Hanaoka and S. Takata, “Demagnetization analysis of additional permanent magnets in salient-pole synchronous machines with damper bars under sudden short circuits,” *IEEE Trans. on Ind. Electron.*, vol.59, no.6, pp. 2448 - 2456, 2012.

[2] J.D McFarland and T.M. Jahns, “Investigation of the rotor demagnetization characteristics of interior PM synchronous machines during fault conditions” *Energy Conversion Congress and Exposition (ECCE)*, IEEE 2012, pp. 4021 - 4028, 2012.

[3] S. Ruoho, J. Kolehmainen, J. Ikaheimo and A. Arkkio, “Interdependence of demagnetization, loading, and temperature rise in a permanent-magnet synchronous motor” *IEEE Trans. on Magn.*, vol.46, no.3, pp. 949 - 953, 2010.

[4] K.C. Kim, K. Kim, H.J. Kim and J. Lee, “Demagnetization Analysis of Permanent Magnets According to Rotor Types of Interior Permanent Magnet Synchronous Motor” *IEEE Trans. on Magn.*, vol.45, no.6, pp. 2799 - 2802, 2009.

[5] C. Kral, R. Sprangers, J. Waarma, A. Haumer, O. Winter and E. Lomonova, “Modeling demagnetization effects in permanent magnet synchronous machines” *Electrical Machines (ICEM), 2010 XIX International Conference*, pp. 1 - 6, 2010.

[6] S. Ruoho and A. Arkkio, “Partial Demagnetization of Permanent Magnets in Electrical Machines Caused by an Inclined Field” *IEEE Trans. on Magn.*, vol.44, no.7, pp. 1773 - 1778, 2008.

[7] S. Ruoho, E. Dlala and A. Arkkio, “Comparison of Demagnetization Models for Finite-Element Analysis of Permanent-Magnet Synchronous Machines” *IEEE Trans. on Magn.*, vol.43, no.11, pp. 3964 - 3968, 2007.

[8] S. Zeze, T. Todaka and M. Enokizono, “Improvement of rotor structure of concentrated surface permanent magnet synchronous motor” *Electrical Machines and Systems, 2009. ICEMS 2009*, pp. 1 - 6, 2009.

[9] A. Kallaste, A. Kilk, A. Belahcen, T. Vaimann, K. Janson, “Demagnetization in Permanent Magnet Slotless Generator Using Halbach Array.” In: Proceedings of the 13th International Scientific Conference Electric Power Engineering 2012: EPE 2012, 2012, pp. 1053 – 1057, 2012

[10] K. Halbach, “Design of permanent magnet multipole magnets with oriented rare earth cobalt material,” Nucl. Instrum. Methods, vol. 169, pp. 1–10, 1980.

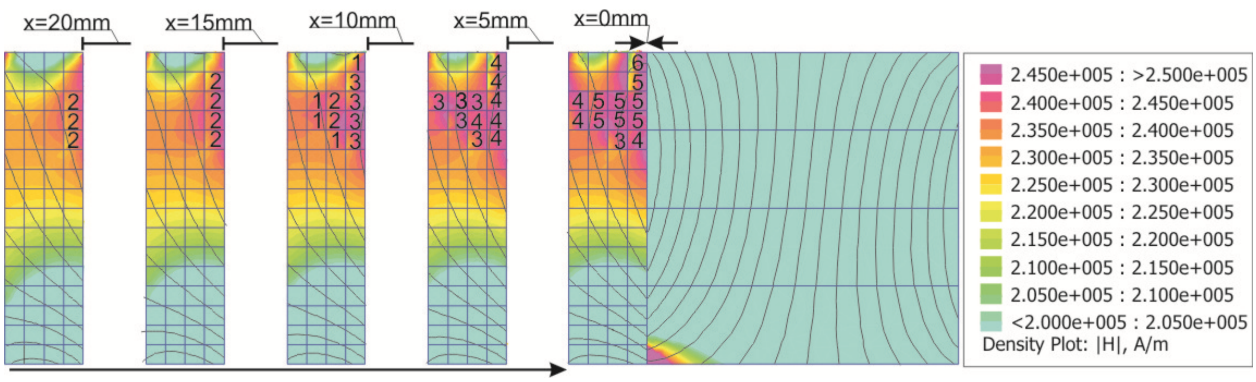

Fig. 3. Computed magnetic field strength from the dynamic simulation at five different positions of the side magnet during its approach to the main magnet.