**CH-07**

# Augmented temperature degrading effect of rare earth magnets arranged in segmented Halbach arrays.

*O. Winter*[1], C. Kral[1], E. Schmidt[2]
*1. Mobilty Department - Electric Drive Technologies, AIT Austrian Institute of Technology, Vienna, Austria; 2. Institute of Energy Systems and Electrical Drives, Vienna University of Technology, Vienna, Austria*

The temperature effects of rare earth magnets arranged in Halbach arrays are of mayor interest for evolved torque production in electric machines.
The objective of this paper is the analysis of temperature dependent nonlinear characteristics of Halbach arrays. A detailed investigation of the flux distribution within the magnets and air-gap is performed by means of Finite Element Analysis (FEA). The resulting field pattern of the magnetic flux density is shown in Figure 1.
In standard applications magnets are basically always used in easy axis directions. Within 90° Halbach arrays, only the in gap magnets carry the flux in the easy axis direction. The pole magnet flux leaves the magnets sideways which leads to an unbalanced flux density distribution within the magnet specimen. Therefore, 2D FEA is employed using typical manufacture data such as nonlinear, temperature dependent demagnetization characteristics as shown in Fig. 2. In order to verify this manufacturer data, magnetic flux density between two magnets in easy axis direction were measured for various temperatures. The setup consists of a Hall probe and a climate cabinet. It is shown that the measured air-gap flux density degrades due to temperature rise by 0.13 %/°K, which meets both datasheet and typical literature values.
If the load line for a given magnetic circuit is intersecting the magnet characteristic above the knee at maximum operation temperature, only reversible demagnetization takes place. However, within the Halbach array magnet specimen, local irreversible demagnetization is already present at the maximum operational temperature. Depending on the air-gap distances, this effect occurs even at lower temperatures and this is the main finding of the presented paper.
To study the impact of the described augmented temperature degrading on the operation of linear electric machines, three test cases were modeled with a 2D FEA tool. The magnetic flux density was evaluated at 2 mm and 5mm respectively (Lxmm describes the perpendicular distance between magnet surface and evaluation/Hall probe surface). Figure 3 shows the maximum value over different operating temperatures.
The three test cases were manufactured and placed in a climate cabinet to emulate various working temperatures. After reaching the thermal equilibrium, flux density over distance was recorded. A representative result is given in Figure 4. It is assumed, that the difference between measurement and FEA was caused by magnet material variations and the adhesive gap between the magnets respectively.
The effect of augmented temperature degrading of sintered rare earth magnets arranged in 90° Halbach arrays is presented in this paper. Both 2D and 3D nonlinear Finite Element Analyses provide a detailed insight on effects due to local demagnetization based on typical manufacturer data. Three different Halbach magnet arrangements were fabricated. A Hall probe was moved over the temperature conditioned functional models to receive both magnitude and position of the magnetic flux density in different distances. The comparison of calculation and measurement data validates the occurrence of the described effect. The full paper will cover a detailed measurement setup description and additional discussions on the magnetic flux characteristics.

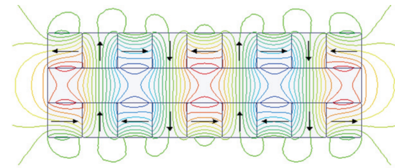

Fig. 1. Double sided Halbach magnet array arrangement without back iron, resulting field pattern

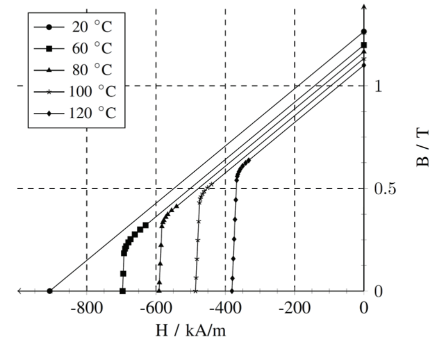


Fig. 2. Typical second quadrant demagnetization data, material grade N40, maximum operation temperature 80°C

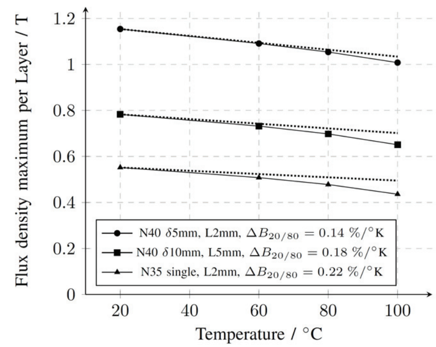


Fig. 3. FEA result for three different 9 pieces Halbach arrangements and materials, (N40 double airgap 5mm, N40 double airgap 10mm, N35 single), Lxmm represents the evaluation distance, dotted line indicates 0.13%/°K theoretical decrease

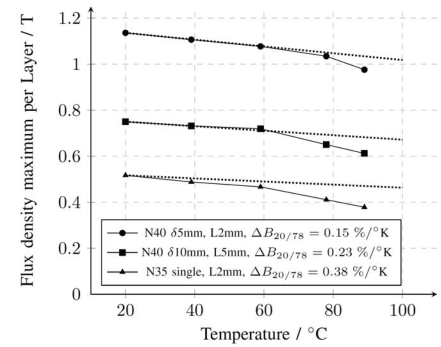


Fig. 4. Measurement result for three different Halbach arrangements (consisting of 9 magnet pieces) and materials, (N40 double airgap 5 mm, N40 double airgap 10 mm, N35 single); Lxmm represents the evaluation distance, dotted line indicates 0.13%/°K theoretical decrease