Temperature-dependent Demagnetisation of Segmented Halbach Arrays

Oliver Winter*, *Student Member*, IEEE, Hannes Lacher*, Christian Kral*, *Senior Member*, IEEE,
Erich Schmidt§, *Member*, IEEE

*AIT Austrian Institute of Technology, Mobility Department, Electric Drive Technologies, Vienna, Austria
§Vienna University of Technology, Institute of Energy Systems and Electrical Drives, Vienna, Austria

Abstract—**Temperature degrading of magnet material is of mayor interest in many applications. Segmented rare earth Halbach arrays are subject to an augmented temperature degrading effect due to local demagnetisation. This paper presents results using a parameter-based material demagnetisation model. Measurement results of high temperature Halbach arrays are validated with 2D FEA.**

Index Terms—**Demagnetization, finite element methods, permanent magnets, rare earth metals, temperature degrading**

I. INTRODUCTION

Halbach arrays were originally developed for synchrotron undulators and multipoles [1]. The changing magnetization direction along the array causes flux concentration at one side of the array (cf. Fig. 1). Single arrays are used in Maglev applications and levitated planar actuators [2], double sided arrays, such as shown in Fig. 1 can be applied to axial flux permanent magnet machines [3]. During the development of an air cored axial flux motor with segmented rare earth Halbach arrays [4], the augmented temperature degrading effect was observed and documented using low cost functional material models [5]. Furthermore, vendor specific B-H demagnetisation characteristics for a few temperatures were used for 2D FEA calculations, such as shown in Fig. 2. It was shown, that N40 magnet material (maximum operational temperature 80°C) was not applicable for this defined maximum temperature. Operational temperatures except those specified by the vendor characteristics could not be analysed, because a temperature-dependent material model with non-linear characteristics was not available. Therefore an advanced demagnetisation material model is used in this work to investigate the application of high temperature magnet material in segmented Halbach arrays, e.g. N40SH (maximum operational temperature 150°C).

II. FEA DEMAGNETISATION MATERIAL MODEL

The sensitivity of magnet material to temperature changes can be modeled by linear functions for the remanent flux density B_r and the intrinsic coercivity, H_{ci}

$$B_r = B_r(T_0)(1 + \alpha(T - T_0)) = B_r(T_0) X(T), \quad \text{(1a)}$$

$$H_{ci} = H_{ci}(T_0)(1 + \beta(T - T_0)) = H_{ci}(T_0) Y(T). \quad \text{(1b)}$$

The coefficients α and β are usually provided by the manufacturer. It is shown in [6], that the temperature dependent
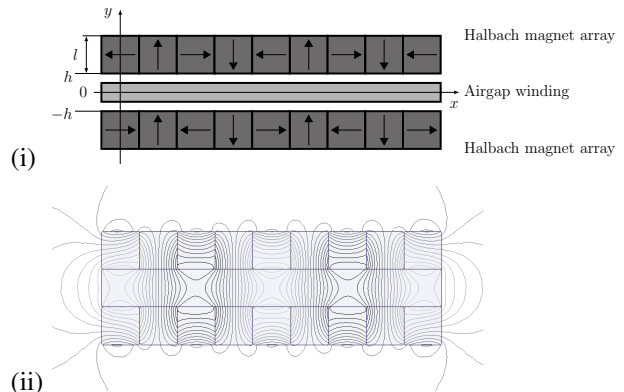

Fig. 1. Double sided Halbach magnet array arrangement without back iron, (i) magnetization pattern, (ii) magnetic flux lines, [5].

J-H characteristics can be approximated by

$$J(H, T) = X(T) \left(a_0 \tanh\left(\frac{H + Y(T) H_{ci}(T_0)}{Y(T) c_0} \right) + a_1 \tanh\left(\frac{H + Y(T) H_{ci}(T_0)}{Y(T) c_1} \right) \right), \quad \text{(2)}$$
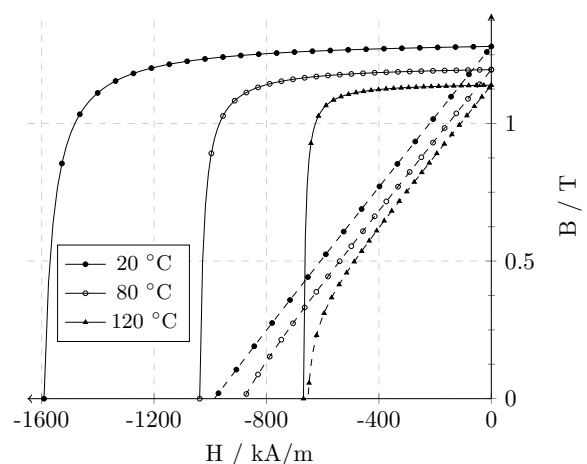

Fig. 2. Typical second quadrant demagnetization characteristics of B (dashed) and the corresponding polarization (intrinsic flux density) J versus field strength H, material N40SH, maximum operational temperature 150°C
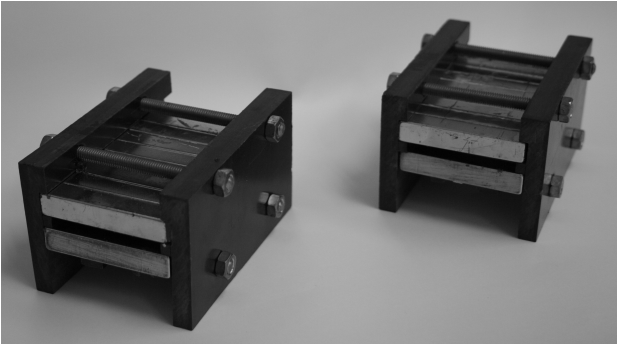
Fig. 3. Functional models, double sided Halbach magnet arrays, N40SH and N40UH grade, (2×9 pieces, 10×10×55 mm each), air-gap δ = 5 mm
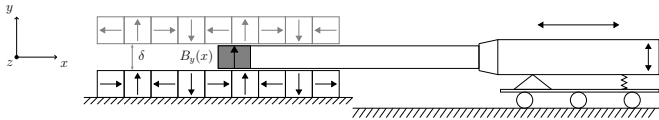

Fig. 4. Measurement principle, several axial hall probes on a test carriage.

where $X(T)$ and $Y(T)$ are defined in (1). The coeffcients a_0, a_1, c_0 and c_1 are derived by nonlinear curve fitting. The procedure to obtain the B-H demagnetization characteristics from $B = J + \mu H$ for an arbitrary temperature is implemented in the used FEA software [6]. The 2D FEA model consists of approximately 8.000 second order tetrahedral elements.

III. FUNCTIONAL MODELS AND MEASUREMENT

In order to proof the augmented temperature degrading for high temperature grade materials, functional models with N40SH and N40UH magnets (150°C and 180°C maximum operational temperature, respectively) were manufactured, as shown in Fig. 3. The functional models (thermally stabilized to the operational temperature in a climate cabinet) were placed on a test bench and a test carriage (including several Hall probes) were inserted to measure the flux density (cf. Fig. 4). The maximum flux density in the center of the air gap was used to compare different temperature levels, as indicated in Fig. 5. In this figure, experimental and numerical results are compared for the functional model (double sided Halbach array). Both 2D FEA and measurement results show the augmented temperature degrading effect, already well below the typical maximum operational temperature. More specifically, the deviation from the linear characteristics lead to irreversible demagnetisation and hence to a minor flux density. Since the measurement and FEA results show qualitative consistency ($\alpha = -0.10\,\%/°C$, $\beta = -0.55\,\%/°C$), the deviation of the amplitude may have several reasons.

The B-H curve provided by the vendor may already deviate from the real B-H curve. Apparently, local irreversible demagnetization occurs in the Halbach array at room temperature when the array gets assembled. This topic will be covered in the full paper.
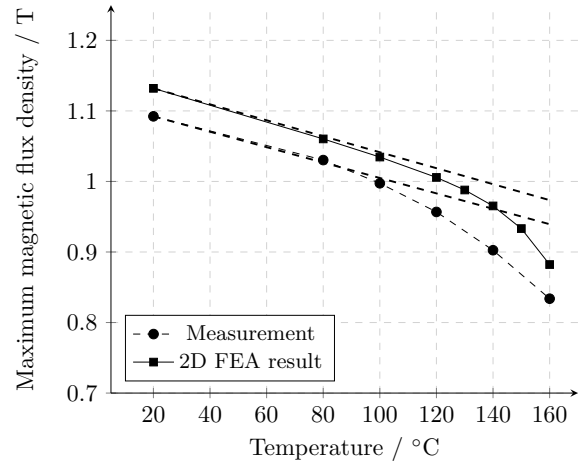

Fig. 5. Comparision of 2D FEA and measurement results for N40SH grade, maximum operational temperature 150°C, irreversible demagnetization occurs at about 100°C, dashed line indicates $-0.10\,\%/°C$ theoretical decrease.

IV. CONCLUSION

This paper describes the application of a linear demagnetisation material model for the validation of the augmented temperature degrading effect in Halbach arrays. The results show good agreement with measurements on segmented Halbach arrays consisting of high temperature rare earth magnets. With this method, appropriate maximum operational temperatures for Halbach applications are derived. The full paper will cover additional material grades, the demagnetisation behaviour during assembly and a detailed description of the measurement setup.

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