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Investigation of the Impact of the Operational Temperature on the Performance of a Surface Permanent Magnet Motor

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Abstract. This paper investigates the impact of different operational temperatures on the performance of a surface permanent magnet (SPM) machine with neodymium-iron-boron (NdFeB) magnets for electric drive applications. The field distribution of the machine for various temperatures is depicted and a comparison of the field distribution in the air gap and the machine output characteristics is performed. On a second step the effect of rotor skew is investigated.

Introduction

Permanent magnet machines are widely used in variable speed drive applications, due to their inherent advantages of high efficiency, high reliability, high torque density and robustness [3]. SPM machines with NdFeB magnets have attracted increasing interests among researchers and designers in many high performance applications and the NdFeB material is often referred as one of the most advanced permanent magnet material available today [1]. It has an excellent price per unit of energy product ratio, allowing small shapes and sizes with high magnetic fields. However, with its different applications and operational environment, the impact of the different operational temperatures on the overall machine system performance is dramatic, and requires further investigation [4]. The objective of this paper is to present the detailed investigation on this impact.

Temperature effects of the NdFeB magnet

The temperature-dependent demagnetization characteristics of a typical NdFeB magnet are illustrated in Fig.1 [2]. With the corresponding demagnetization curves of the material for operating temperatures ranging from 20 ^{o}C to 140 ^{o}C, it can be observed that the material remanent flux density will be decreased with temperature increment. As long as the operating point of the magnet does not go beyond the linear portion of its demagnetization curve, such decrement effect is reversible when the temperature goes down and the flux density will then go back to the original value.

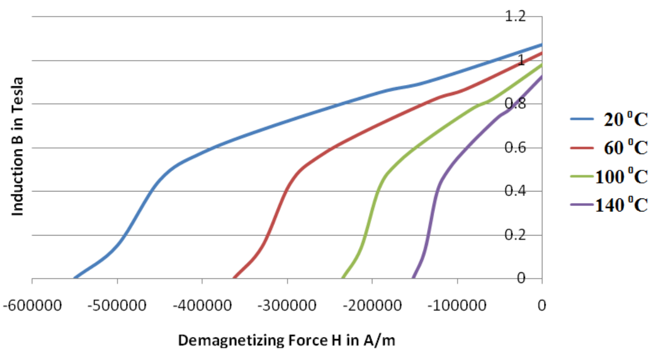

Fig. 1. Demagnetization characteristics of a typical NdFeB magnet

Hence, the magnet shall never be designed to operate beyond its linear part of demagnetization curve. It is also known that the remanent flux density and intrinsic coercivity of PMs will decrease with the temperature increasing, in their normal operating temperature range.

Results and Discussion

The effect of the operational temperature on the NdFeB magnets has been investigated on a 2.5-kW, 24-pole surface permanent-magnet machine prototype with NdFeB magnets. The prototype has NdFeB magnets without rotor skew and an output power of 2kW and is shown in Fig. 2.

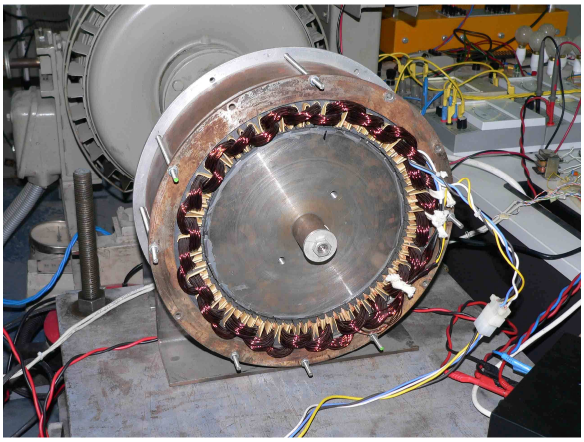

Fig. 2. Surface permanent magnet machine prototype

In a first step, no rotor skew has been considered. The flux density distribution in the air gap of the SPM machine is calculated for different operational temperatures using 2D FEM analysis and based on the aforementioned PM material information. The distribution of the machine flux density and the distribution of the machine flux for two different operational temperatures, 20 ^{o}C and 100 ^{o}C respectively, is illustrated in Fig.3 – Fig. 6. The distribution of the machine flux density in the air gap for four operational temperatures is depicted in Fig.7.

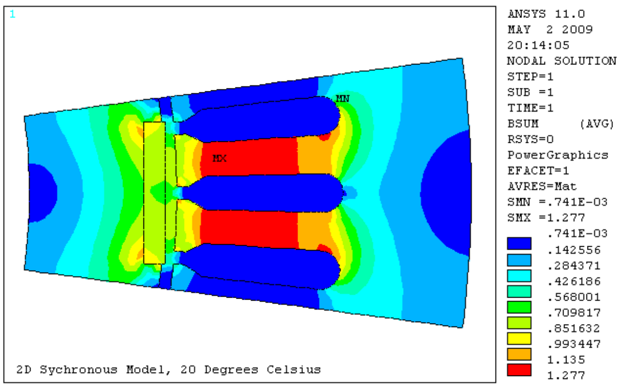

Fig. 3. Flux density distribution distribution for 20 ^{o}C operational temperature

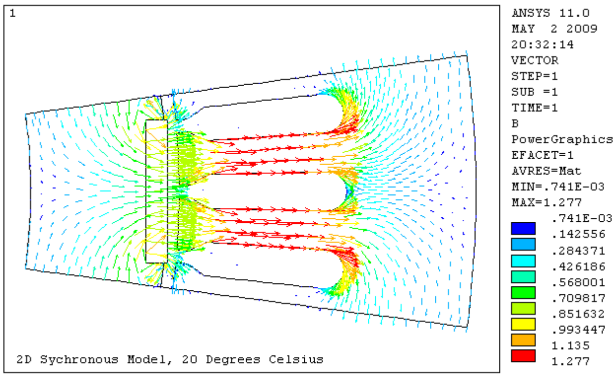

Fig. 4. Flux distribution for 20 °C operational temperature

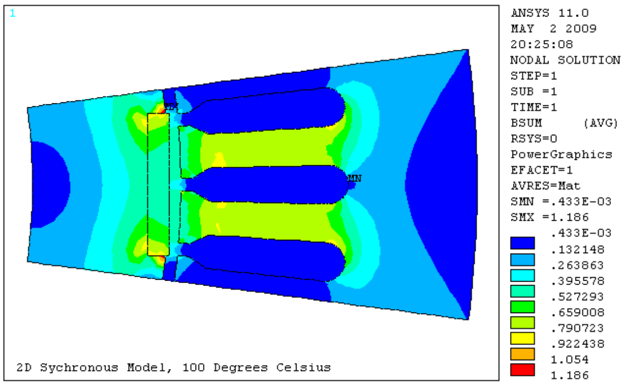

Fig. 5. Flux density distribution for 100 °C operational temperature

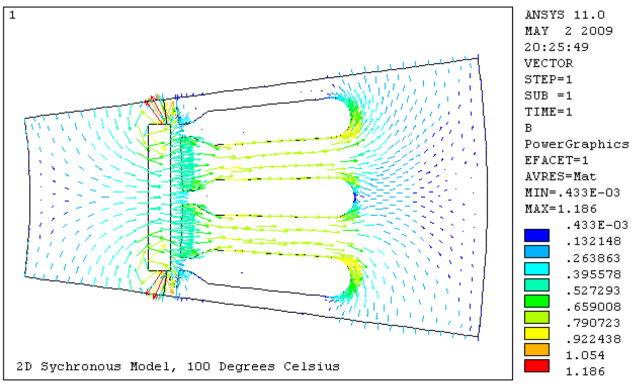

Fig. 6. Flux distribution for 100 °C operational temperature

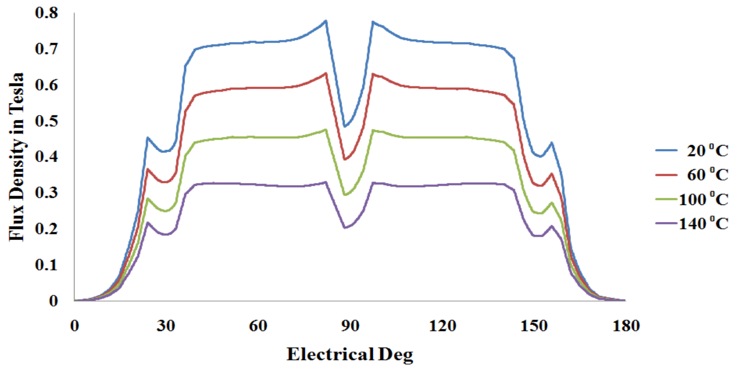

Fig. 7. Distribution of flux density in the air gap for different operational temperatures

It is evident that the rise of the operational temperature causes a significant decrease of the air gap flux density, thus deteriorating the machine's overall performance, resulting in acceptable characteristics up to 100 ^{o}C temperature.

Moreover, the field in the machine has been computed byusing a 3-D FE representation. Fig. 10 shows the simulated flux distribution in the SPM machine without rotor skew, obtained by a 3-D simulation. The results are in relatively good agreement with the ones obtained by standard 2-D FEM simulation, while the smaller values of the 3-D analysis are due to the end effects.

In addition, the skewed machine 3-D simulation has been performed. Fig. 9 shows the motor geometry with rotor skew. The same case with rotor skew has been equally simulated by a 3-D FEM model in order to model the inclination of the magnets and the results are shown in Fig. 11.

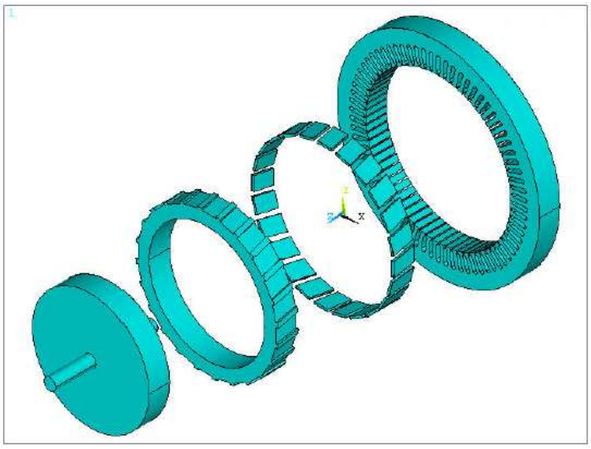

Fig. 9. Motor geometry with rotor skew (3-D)

The detailed flux density distribution in the air gap with and without rotor skew obtained by the 3-D FEM model is shown in Fig. 12 and Fig. 13, respectively. The simulation results shown are for an operational temperature of 20 ^{o}C. The obtained results show that the rotor skew consists an advantageous solution for torque ripple reduction.

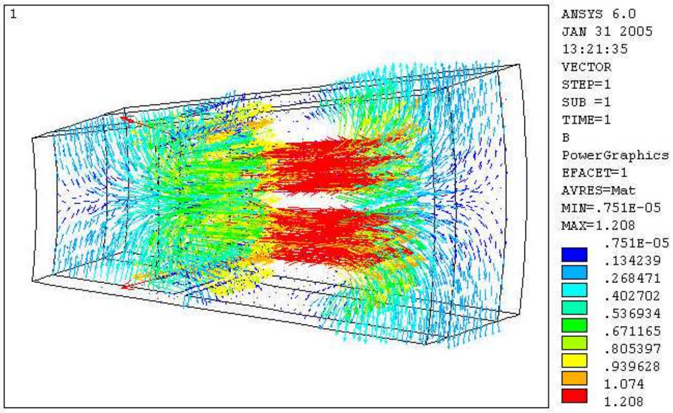

Fig. 10. Flux distribution for 20 ^{o}C operational temperature – 3D model without rotor skew

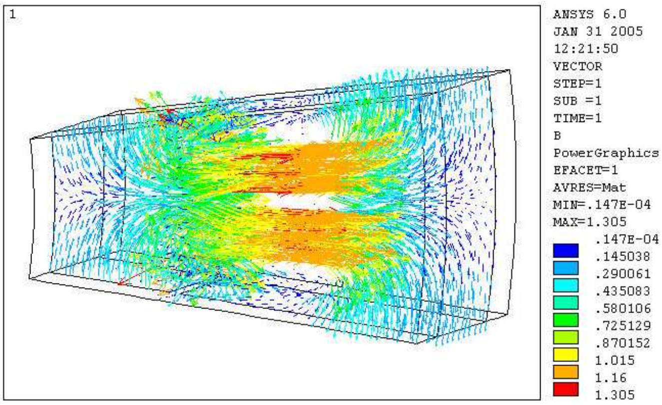

Fig. 11. Flux distribution for 20 ^{o}C operational temperature – 3D model with rotor skew

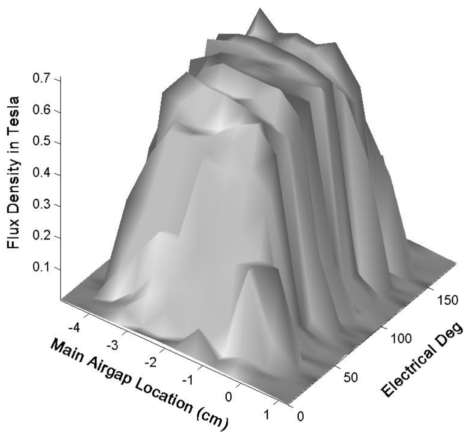

Fig. 12 . Flux density distribution in the the middle of the air gap for 20 ^{o}C operational temperature – 3D model without rotor skew

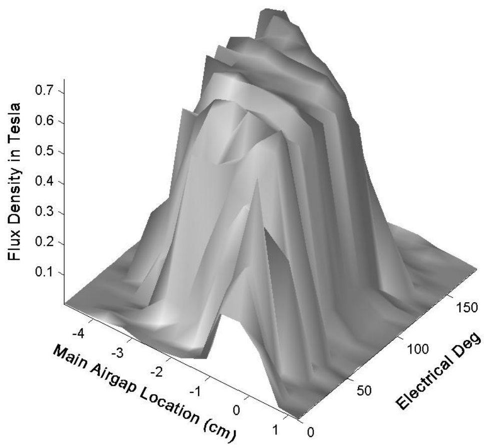

Fig. 13. Flux density distribution in the the middle of the air gap for 20 ^{o}C operational temperature – 3D model with rotor skew

Conclusions

The temperature dependent characteristics of a SPM machine designed for drive applications have been discussed in this paper. Results show that the machine's air gap flux density will be down-rated with rising operational temperatures. In addition, the effect of rotor skew for different operational temperatures was considered, and its applicability for SPM machines has been validated.

References

[1] A. Wang, H. Li and C-T. Liu, "On the material and temperature impacts of interior permanent magnet machine for electric vehicle applications", IEEE Trans. Mag., vol 44,, no. 11, pp. 4329-4332, Nov. 2008.

[2] Hitachi Metals Ltd, "Demagnetization curve of magnet S54_NdFeB", 2009, [Online]. Available: http:\\www.hitachi-metals.co.jp.

[3] T. M. Jahns and S. H. Han, "Design and experimental verification of a 50 kW interior permanent magnet synchronous machine," Proc. IEEE IAS Annu. Meet., Sep. 2007, pp. 1941-1948.

[4] S. Chen, K.J. Binns, Z. Liu and D. W. Shimmin, "Finite element analysis of the magnetic field in rare-earth permanent magnet systems, with consideration of temperature dependence," IEEE Trans. Mag., vol 28,, no. 2, pp. 1303-1306, Mar. 1992.