INTERMAG 2014
DIGEST BOOK

More than 1600 authors

22. April 2014

AA-11 Ferromagnetic loss computation objective to rigorous understanding and further enhancement of electrical machines

Kay Hameyer , Daniel Eggers, David Franck, Marco Hombitzer, Georg von Pfingsten, Simon Steentjes
RWTH Aachen University

Abstract

The magnetic circuits of electrical machines are nowadays highly utilized. This statement is true for the magnetic as well as the electric circuit and depicts that significant enhancements of electrical machines are difficult to achieve. In this contribution we will focus on the discussion on parasitic loss mechanisms of the electrical machines' ferromagnetic material.

Introduction

Most of the electric motors are speed variable drives. The material utilization is therefore depending on the drive cycle of the machines' application. Optimizing the drive for a specific working point is not constructive. For instance in order to determine the overall efficiency for an entire drive cycle all working points have to be considered including their frequency of occurrence. These findings are of course not new and are considered usually by the motor designers. However, the rigorous knowledge of the different loss mechanisms, e.g. the iron losses, can enable the possibility to exploit specific loss effects to enhance the drive in particular working points or for specific operational conditions. On the other hand the most appropriate material choice can be realized with this specific knowledge [1].

In numerical simulations of electric motors, various material models can be employed to obtain realistic data for the iron losses. In such models, there are basically single components of hysteresis, eddy current and excess losses [2-4] specified. Specific empiric factors calibrate such formulae to the particular material operated at defined frequency and polarization. In highly utilized and speed variable drives, this approach is rather inaccurate and therefore inappropriate [5].

Parasitic loss mechanism

To further enhance the properties of electric motors the accurate determination by idealized model assumptions of the locally distributed iron losses alone is not sufficient [5,6]. Other loss generating effects have to be considered and it must be possible to distinguish between the causes of particular loss components. In fact, the parasitic loss mechanisms which additionally contribute to the total losses are originated next to the fundamental frequency, from field harmonics, from the ferromagnetic material's non-linearity, from rotational magnetizations and from effects caused by the machines' manufacturing process or from temperature. Such losses are not explicitly determined in the common models, probably even not specifically contained in the mentioned calibration factors. Effects which are manufacturing or process dependent can e.g. roughly be allocated to the cutting, respectively punching process, to imposed mechanical strain or stress to the material or can be temperature dependent.

Material modeling

An improved estimation of iron losses is indispensable, which is applicable in a wide range of frequency and flux density [5]. Fig. 1 (top) shows a comparison between the state-of-art iron-loss formula and the 5-Parameter-IEM-Formula, which considers phenomenological the material saturation effects. In addition parasitic loss inducing effects, particularly occurring in electrical machines, such as higher harmonics, dc-biased magnetizations and rotational fields need to be taken into account [6, 9]. Likewise, the mechanical properties get more and more important. Firstly, for reasons of yield strength and secondly for processing reasons. The deteriorating effect of material processing, such as guillotine or laser cutting and punching, needs to be included in the iron loss calculation [7,8]. For example, Fig. 1 (bottom) shows the deteriorating effect on iron losses due to cutting and the error made when assuming a non-degraded material.

Examples

Depending on the operating point in electrical machines, copper losses and iron losses make a different share in the overall loss. For high torques the ohmic losses are dominant. For high speeds the iron losses dominate.

The local loss distribution within the machine is important in permanent magnet excited machines.

Although they make a small portion of the overall losses they have to be analyzed because of rotor temperature. Depending on the operating point, the rotor hysteresis losses make a significant share in the rotor iron losses (Fig. 2) [9].

Conclusions

The approach being able to distinguish between different loss mechanisms enables to individually consider particular loss mechanisms in the model of the electric motor particular loss mechanism or not. With this, a sensibility analysis of the model parameter can be performed in such a way, that we obtain information about which loss origin for which working point has to be manipulated by the electromagnetic design of the machine or by the control of the motor's electric quantities to enhance the properties, e.g. the efficiency of the machine.

The understanding of the loss mechanisms in electrical steel is important for machine designers as well as for manufacturers of electric steel.

References

[1] I. Podoleanu, J. Schneider, G. Müller, K. Hameyer, "Software tool for the optimum material choice for induction machines," *OPTIM* , 2002.

[2] G. Bertotti, *Hysteresis in magnetism* , Academic Press, 1998.

[3] C. Steinmetz, ,,On the law of hysteresis (originally published in 1892),“ *Proc. Conf. IEEE* , vol. 72, no. 2, pp. 197-221, 1984.

[4] S. E. Zirka, Y. I. Moroz, P. Marketos, A. J. Moses, "Loss Separation in Nonoriented Electrical Steels," *IEEE Trans. on Magn.* , vol. 46, no. 2, 2010.

[5] S. Jacobs, D. Hectors, F. Henrotte, M. Hafner, M. H. Gracia, K. Hameyer, P. Goes, D. R. Romera, E. Attrazic, S. Paolinelli, ,,Magnetic material optimization for hybrid vehicle PMSM drives,“ *EVS24* , 2009.

[6] S. Steentjes, M. Leßmann, and K. Hameyer, "Advanced Iron-Loss Calculation as a Basis for Efficiency Imrpovement of Electrical Machines in Automotive Application," *Proc. Conf. ESARS* , pp. 1–6, 2012.

[7] F. Henrotte, J. Schneider, K. Hameyer, ,,Influence of the manufacturing process in the magnetic properties of iron cores in induction machines,“ *WMM* 2006.

[8] S. Steentjes, K. Hameyer, M. Bednarz, S. Vogt, W. Volk, J. Dierdorf, G. Hirt, ,,Influence of material processing steps annealing and cutting on magnetic materials' properties relevant for electrical machine design,“ *FTF 2013* .

[9] S. Steentjes, G. von Pfingsten, M. Hombitzer, K. Hameyer, "Iron-loss model with consideration of minor loops applied to FE-simulations of electrical machines," *IEEE Trans. on Magn.* , vol. 49, no. 7, 2013.