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Enhanced iron-loss model with consideration of minor loops applied to FE-simulations of electrical machines

Simon Steentjes, Georg von Pfingsten, M. Hombitzer and Kay Hameyer

RWTH Aachen University, Institute of Electrical Machines, Schinkelstr. 4 in D-52062 Aachen, Germany
E-mail: Simon.Steentjes@IEM.rwth-aachen.de

Abstract:

Usually the design process of an electrical machine is based on analytical preliminary computation of the electro-magnetic circuit followed by FE-simulations for refinement. For an enhanced design the knowledge about the soft magnetic material's behavior for various operating points is eminent. This includes the magnetizability of the material as well as the estimation of the iron losses which are caused by alternating magnetic flux in the rotor and stator material.

Accurate iron loss estimation is essential in order to achieve a high efficiency and an advantageous utilization of the soft magnetic material in electrical machines, i.e. power density.

The iron losses are calculated by a post-processing of FE-simulations. The transient FE-simulation generates for each finite element output data of the flux density in each time step. Based on these generic time dependent magnetic flux density waveforms, the iron-loss model needs to yield reliable loss data. Common empirical loss models are sufficiently accurate for low flux densities and frequencies if neglecting the harmonics in magnetic flux. Thus, these models are not suitable for highly saturated materials, higher harmonics, and frequencies above 400Hz [1, 2]. Electrical machines for automotive application are operating in the range of $1.3T \leq B \leq 1.8T$ for the flux densities and magnetization frequencies $f \geq 400Hz$. Therefore, the IEM recently developed a 5-parameter-formula [1, 2], which resolves this limitation. In this paper, the consideration of arbitrary magnetic flux density waveforms and minor loops is investigated. First of all a detailed analysis of the influence of harmonics and the resulting minor loops on the iron-losses at various frequencies and flux density amplitudes is performed. Additional attention is paid to the influence of the phase angle of the higher harmonics on the iron losses. Consequently, a commonly used empirical formula for minor loop loss calculation [3] is evaluated. Finally the aforementioned effects are included and the IEM-Formula is applied to calculate the losses in a permanent magnet synchronous machine for automotive application. The predicted loss values are compared to measurements.

References:

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