HX-12

Comparison of motor stator teeth built of soft magnetic composite and laminated silicon steel sheets in an axial flux permanent magnet synchronous machine.

B. SCHEERLINCK[2,1], P. SERGEANT[2,1]
1. Industrial Technology and Construction, Ghent University, Ghent, Belgium; 2. Electrical Energy, Systems & Automation, Ghent University, Ghent, Belgium

The stator of a Yokeless And Segmented Armature (YASA) Axial Flux Permanent Magnet Synchronous Machine (AFPMSM) is built of individual core elements, excited by concentrated windings. Nowadays, these core elements are mostly constructed by use of Laminated Silicon Steel Sheets (LSSS). The use of LSSS reduces excessive eddy currents, although two types of significant eddy-current effects remain [1]. The first type is due to the main magnetic field parallel to the laminations, which induces narrow current loops within each individual sheet. The second type comes from the magnetic stray field, also called the fringing field, which has components perpendicular to the laminations, and induces large current loops parallel to the sheets. As an alternative to laminated sheets, Soft Magnetic Composites (SMC) can carry 3D flux paths and may in some applications increase the torque/weight ratio of the machine [2].
This paper compares the iron losses generated by the concentrated excitation windings for the AFPMSM stator core elements constructed with LSSS and SMC. The mentioned two types of eddy current losses for LSSS are taken into account.
All flux density distributions are calculated by a 3D non-linear finite element method (FEM) model in the time domain, for various frequencies and different magnitudes. The FEM model uses second order tetraeder mesh elements together with the T- formulation as described in [3].
To accurately compute the two types of eddy currents, the first few sheets closest to the excitation winding are explicitly modelled in FEM as individual domains, separated by thin insulating (coating) layers. Indeed, the largest energy dissipation due to stray fields (fields closing through the air and entering the lamination perpendicularly) in LSSS stacks takes place in the first few sheets closest to the excitation winding. The remaining middle part of the laminated stack is modelled as a homogenized bulk material with anisotropic magnetic and electric properties, as suggested in [4]. The classical losses in this homogenized middle part are calculated separately by use of a 1D finite difference model of half the lamination thickness. For the core elements made of SMC, the classical losses are directly calculated using the 3D non-linear FEM model. Evidently, no laminations need to be modelled here .For both materials single valued *BH*-curves are used, measured on Epstein frames. Hysteresis and excess losses are calculated using a loss model fitted on the basis of those Epstein frame measurements.
In order to evaluate the FEM results, a rigid dedicated experimental setup without moving parts is built, as shown in figure 1. The air gap can be varied. For each material, four stacks are positioned at a pole width of 50 mm from each other. The yoke with a thickness of 20 mm is larger than the real back iron of a permanent magnet synchronous motor, in order to keep the losses of the back iron low compared to those in the lamination stack. Besides the copper, lamination stacks and/or SMC teeth, all surrounding material is poly-amid.
The 3D model is evaluated and compared with the measurement data for the two types of materials. The right side of figure 1 shows the measured total iron losses of the complete setup for the two types of materials used as stator teeth for a frequency of 50 and 100Hz. The left side of figure 2 shows the eddy current density vectors induced by the stray fields in the top sheet of a LSSS stack. The right side of figure 2 shows the losses due to stray fields in function of time in the individual top sheets, with the sheet numbering starting from the top of the LSSS stack. The difference between losses with SMC and FeSi is smaller than predicted based on manufacturer data obtained on Epstein frame, because the magnetic field and eddy current distribution are more complicated. The full paper will present a detailed analysis of the contribution of stray field caused eddy currents in the LSSS.

[1] H. De Gersem, S. Vanaverbeke, and G. Samaey, “Three-Dimensional-Two-Dimensional coupled model for eddy currents in laminated iron cores,” IEEE Trans. Magn., vol. 48, no. 2, pp. 815–818, feb 2012.
[2] G. Cvetkovski and L. Petkovska, “Performance Improvement of PM Synchronous Motor by Using Soft Magnetic Composite Material,” IEEE Trans. Magn., vol.44, no.11, pp.3812,3815, 2008.
[3] O. Biro, K. Preis, and I. Ticar, “A FEM method for eddy current analysis in laminated media,” COMPEL, vol. 24, no. 1, pp. 241–248, 2005.
[4] Z. Cheng, N. Takahashi, B. Forghani, G. Gilbert, J. Zhang, L. Liu, Y. Fan, X. Zhang, Y. Du, J. Wang, and C. Jiao, “Analysis and Measurements of Iron Loss and Flux Inside Silicon Steel Laminations,” IEEE Trans. Magn., vol. 45, no. 3, pp. 1222–1225, 2009.

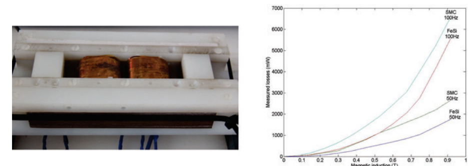

Fig. 1: A rigid dedicated experimental setup without moving parts, and the measured total iron losses of the complete setup for the two types of materials used as stator teeth for a frequency of 50 and 100Hz.

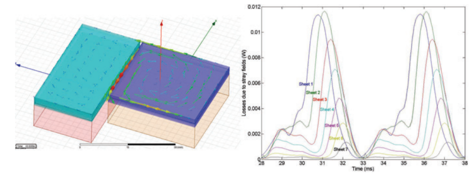

Fig. 2: Eddy current density vectors induced by the stray fields in the top sheet of a LSSS stack, and the losses due to stray fields in function of time in the individual top sheets with the sheet numbering starting from the top of the LSSS stack .