2D Eddy Current Analysis in Plane of Laminated Ferromagnetic Media

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Abstract

Introduction:
Laminated media are intended to conduct the magnetic flux in the plane (high resistance to limit the eddy currents). When fringing flux falls in perpendicular to the plane, the surface for the eddy currents is no longer small. This will cause eddy current losses, which will reduce the efficiency of the application. This fringing flux can be produced by the winding around the stack or in case of permanent magnet synchronous machines by flux from the permanent magnets on the rotor . Also magnetic saturation of a sheet will result in flux travelling from one sheet to another, causing flux perpendicular to the plane of the sheet [1], [3].
Use of COMSOL Multiphysics®:
A FEM model for in plane losses in laminated ferromagnetic media due to fringing flux perpendicular to the plane is presented. This is done for one tooth of an axial flux permanent magnet motor with concentrated windings. Instead of using a homogenization method [2], all details of the laminated media are considered to become an accurate model. In order to reduce calculation time, a 2D model and a simplified geometry with proper symmetry is used. By this way the geometry is one fourth of a rectangular tooth in closed magnetic circuit by use of a yoke. The isolation (coating and air) between the sheets is modeled by use of 'thin low permeability gaps'. The sum of the induced eddy currents must be zero in each individual sheet, this is obtained by use of the 'single turn coil domain' with total current zero applied to each sheet.
Results:
When the norm of the magnetic induction is plotted, it can be seen that the main flux is the same in all sheets, but the top sheets saturate because the flux follows the path with highest permeability. Different frequencies are studied. When the frequency increases, the eddy currents increase which results in higher losses. At higher frequencies, the losses aren't no longer quadratic with the frequency, because the magnetic reaction field produced by the eddy currents compensating the magnetic fringing field can't be neglected. This is shown in figure 1.
Different widths of the air gap (width between yoke and stack) are studied, when the air gap width increases, more fringing flux falls in perpendicular to the sheet, which causes more eddy currents which results in more losses. The change of the magnetic field can be seen by plotting contours of the 'magnetic vector-potential in the out of plane direction'. This change can be seen by comparing figure 2 where the air gap is 1mm with figure 3 where the air gap 5mm.
Conclusion:
The 2D FEM model provides an accurate and fast prediction of the eddy current losses caused

by fringing flux. These losses are overestimated in this 2D model because the leakage flux in the direction perpendicular to the modeling plane is not taken into account.

Reference

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[2] K. Muramatsu, T. Okitsu, H. Fujitsu and F. Shimanoe "Method of Nonlinear Magnetic Field Analysis Taking Into Account Eddy Current in Laminated Core" IEEE Trans. Magn., vol. 40, no 2, pp. 896-899, March 2004.
[3] T. Nakano , Y. Kawase , T. Yamaguchi , M. Nakamura , and N; Nishikawa "3-D Finite Element Analysis of Eddy Current in Laminated Cores of the Interior Permanent-Magnet Motor" IEEE Trans. Magn., vol. 49, no 5, pp. 1945-1948, May 2013.

Figures used in the abstract

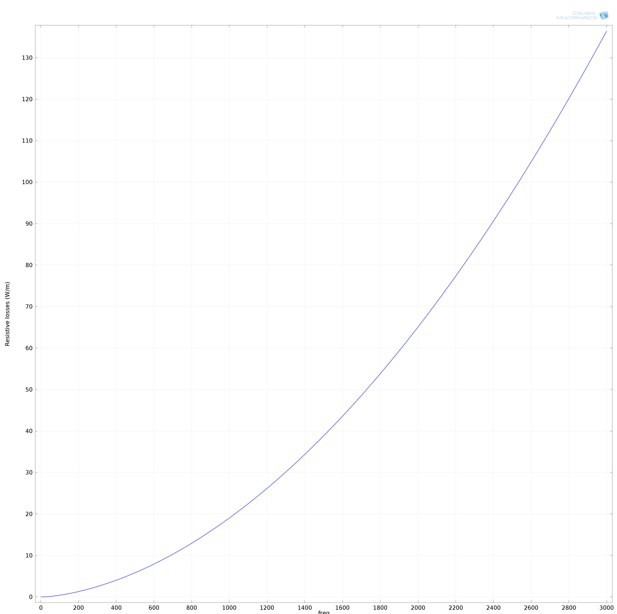

Figure 1: Losses in function of frequency

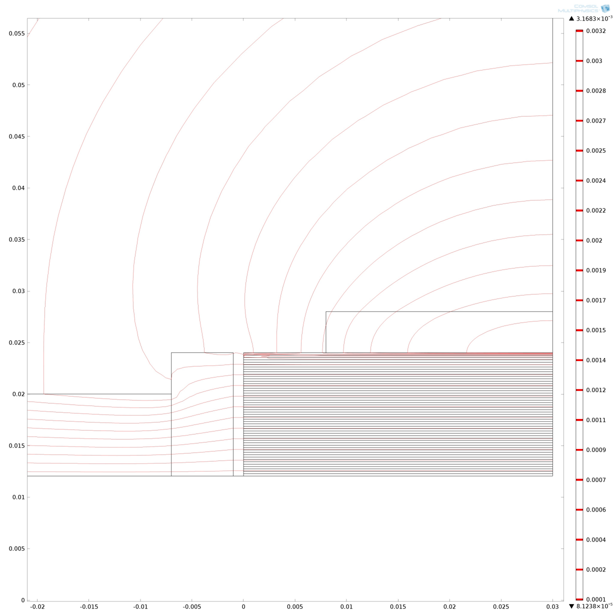

Figure 2: Contour of the magnetic vector potential in the out of plane direction, for an airgap of 1mm

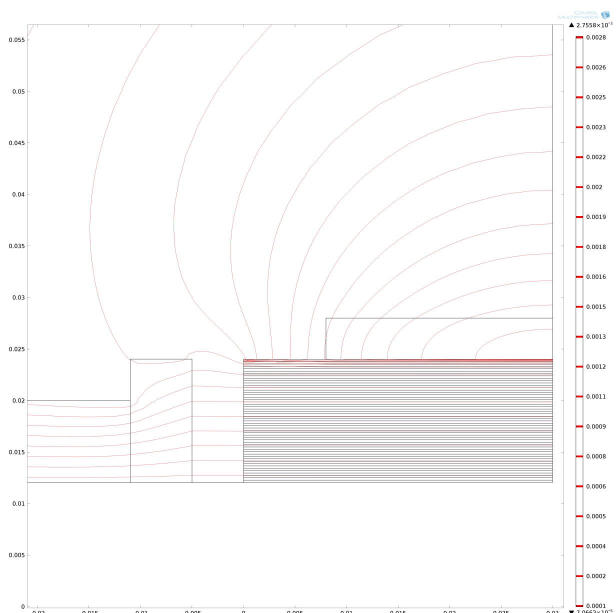

Figure 3: Contour of the magnetic vector potential in the out of plane direction, for an airgap of 5mm