3D Power Inductor: Calculation of Iron Core Losses

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Abstract

Introduction:
Designing magnetic components requires the well-known of electromagnetic losses they lead to. However, the right evaluation of those losses is quite complex because they depend on frequency, amplitude, waveform, geometry and materials' nature. The work proposed in this paper deals with the consideration of 3D geometric effects and material non-linearity to evaluate iron losses in magnetic devices used in power electronics. To carry out this work, we rely upon two existing models of iron losses per unit volume calculation currently used in power electronics (Figure 1). They are volumetric models, but instead of applying them at a macroscopic scale, we have applied them at an element scale to improve the estimation accuracy of iron losses. Furthermore, in order to take account of geometric effects in the corners of the magnetic core, which are the source of local saturation and field's redistribution, it is also necessary to model the non-linearity of the magnetic material. This non-linearity is defined from the initial magnetization curve of the magnetic material.

Use of COMSOL Multiphysics®:
The study was realized on the existing COMSOL Multiphysics® model called "Power Inductor". In order to calculate the magnetic field volumetric distribution inside the iron core, we have used the AC/DC module with Magnetic Field (MF) physics. Three materials have been used, air, copper for the wire, 3F3 Ferroxcube ferrite material for the core. To take into account the non linearity of the ferrite material, we have defined the B(H) curve. Once the volumetric distribution is obtained, thanks to the LiveLink™ for MATLAB®, we have recovered the result in MATLAB® to calculate losses using (SE) and (iGSE) formulas for each element (Figure 2). Note that for the iGSE formula, we need temporal information. So we have repeated the previous steps to obtain the temporal waveform (quasi static assumption).

Results:
The results we present have been obtained by performing our calculation method for two different classical current waveforms in power electronic, a sinusoidal one and a triangular one. The results show well the necessity of taking into account 3D geometric effects, especially on this core geometries where the cross section is not constant along the magnetic path (Figure 3). We can see areas where losses are high, according to the 3D magnetic field distribution. Indeed, we get up to 500% deviation between the classical losses calculation and by considering those effects (Figure 4). Finally, we can also notice on the temporal curves the impact of non-linearity on their shapes.

Conclusion:

The new method presented here allows taking into account with a good accuracy, 3D geometric effects in iron losses calculation, in magnetic components for power electronics. As we have seen, those effects have a manifest contribution. Having a good knowledge of electromagnetic losses is primordial to thermally design a magnetic component and this method aims to improve their conception.

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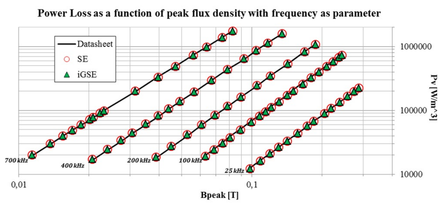
Figures used in the abstract



Steinmetz Equation (SE) :

$$\overline{P_v(t)} = kf^{\alpha}\hat{B}^{\beta}$$

Improved Steinmetz Equation (iGSE) :

$$\overline{P_v(t)} = \frac{1}{T}\int_0^T k_i \left|\frac{dB}{dt}\right|^{\alpha} (\Delta B)^{\beta-\alpha} dt$$

Figure 1: Preliminary validation of theoretical model for unsaturated sinusoidal supplying- 3F3 ferrite at 100°C

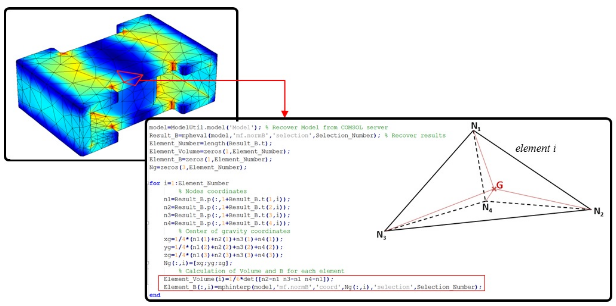
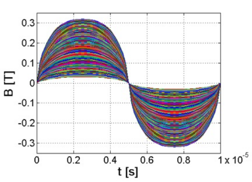
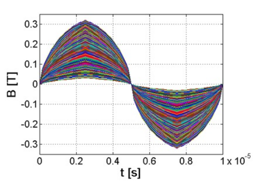


Figure 2: Presentation of the implemented method using LiveLink™ for MATLAB®



SE	$kf^{\alpha}\widehat{B_{av}}V_{tot}$	25,0W
3DSE	$\sum(kf^{\alpha}\widehat{B_{elem}}V_{elem})$	103W
iGSE	$\left(\frac{k_i(\Delta B_{av})^{\beta-\alpha}}{T}\int_0^T\left\|\frac{dB_{av}}{dt}\right\|^{\alpha}dt\right)V_{tot}$	27,2W
3DiGSE	$\sum\left[\left(\frac{k_i(\Delta B_{elem})^{\beta-\alpha}}{T}\int_0^T\left\|\frac{dB_{elem}}{dt}\right\|^{\alpha}dt\right)V_{elem}\right]$	110W



SE	$kf^{\alpha}\widehat{B_{av}}V_{tot}$	25,0W
3DSE	$\sum(kf^{\alpha}\widehat{B_{elem}}V_{elem})$	104W
iGSE	$\left(\frac{k_i(\Delta B_{av})^{\beta-\alpha}}{T}\int_0^T\left\|\frac{dB_{av}}{dt}\right\|^{\alpha}dt\right)V_{tot}$	32,1W
3DiGSE	$\sum\left[\left(\frac{k_i(\Delta B_{elem})^{\beta-\alpha}}{T}\int_0^T\left\|\frac{dB_{elem}}{dt}\right\|^{\alpha}dt\right)V_{elem}\right]$	130W

Figure 3: Example of volumetric distribution of the magnetic flux density and losses inside the iron core

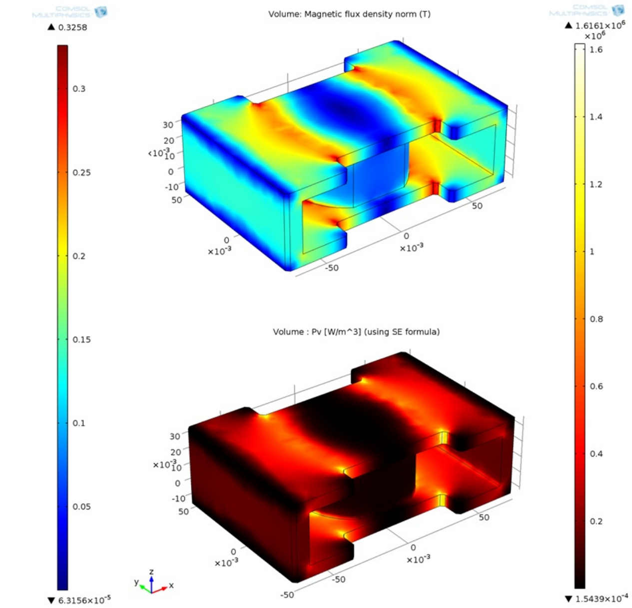


Figure 4: ||B(t)|| for each element (left) and Results of global losses from classical approach and our new approach (right) for two current excitation waveforms : sinusoidal (up) – triangular (down) – triangular (down)al (up) – triangular (down)