A Finite Element Model for Foil Winding Simulation

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***Abstract* - The application of an additional discretisation for the voltage across a foil winding enables the simulation of the particular skin effect of foil conductors while preserving small magnetic meshes.**

I. Introduction

A foil winding consists of a considerable number of layers of foil (Fig. 1). A straightforward model considers all windings separately as massive conductors connected in series. The large differences in dimensions cause large meshes with possibly ill shaped elements [1]. Approximating the foil winding by a filamentary conductor neglects the important current concentrations and according to this, the heating effects at top and bottom of the winding.

I. Foil Elements

Here, a hybrid solid/stranded conductor model is applied. The voltage across the foil winding cross-section is modelled by an additional discretisation with n_f foil elements N_f :

$$V(x) = \sum_{f=1}^{n_f} V_f N_f(x). \tag{1}$$

The support of a foil shape function does not coincide with a single foil winding but may span several foils (Fig. 1b).

The magnetic mesh and the foil mesh are constructed independently. Therefore, meshing the 2D geometry is not influenced by the large differences in dimensions introduced by the foils.

II. Formulation

Three equations are solved simultaneously: the 2D time-harmonic differential equation and two integral relations

$$\int_{\Omega_f} \left(\frac{\sigma}{\ell_z} V - j\omega\sigma A_z \right) d\Omega = \frac{N_t}{\Delta_{tot}} I_{fol} \tag{2}$$

$$\frac{N_t}{\Delta_{tot}} \int_{\Omega_{tot}} V \, d\Omega = V_{ex} \tag{3}$$

forcing the current I_{fol} to be the same in each foil and applying voltage excitation with V_{ex} to the foil winding. Here, A_z is the *z*-component of the magnetic vector potential, ω the pulsation, σ the conductivity, ℓ_z the depth of the model, N_t the number of foils, Ω_f and Ω_{tot} the domains of one foil and of the whole winding and Δ_{tot} the cross-section of the winding. This foil formulation is easily embedded in the field-circuit coupling scheme pointed out in [2]. Both, the magnetic shape functions and the foil shape functions serve as test functions in the Galerkin FE approach. The coupled system matrix is a 3x3 block matrix with a large sparse FE part, a small foil element part and a few circuit equations. The off-diagonal coupling blocks are dense. As the FEs and the foil elements do not share the same supports, the FE procedure has to deal with integrations of arbitrarily overlapping shape functions.

The flux inside a foil winding of a single-phase transformer is compared to the flux density distributions arising in the case of a solid or a stranded conductor (Fig. 1).

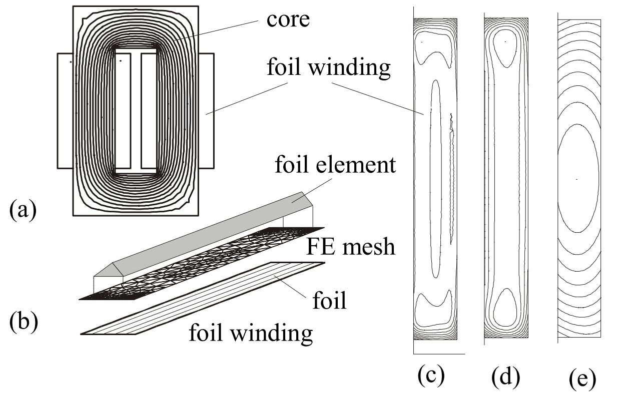

Fig. 1: (a) Foil winding transformer; (b) foil element; (c) flux inside foil winding compared to flux inside (d) solid and (e) stranded conductor.

III. Conclusions

The foil winding model relies upon a foil mesh as a discretisation for the voltage. The coupled approach prevents huge meshes while remaining capable of simulating the current redistribution towards the tips of the foils.

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