Homogenization Techniques for Laminated Core and Soft Magnetic Composites in Magnetic Field Analysis

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1. Introduction

In electrical machines, laminated cores and soft magnetic composites (SMCs) are often used in order to reduce the eddy current losses. In the magnetic field analysis of such machines, the cores are usually modeled by solid ones in order to save computation cost. To take account of the nonlinearity and the eddy currents in steel plates or particles, and the gaps between them in the solid core model, homogenization techniques [1), 2)] are applied. In this paper, the homogenization techniques for laminated core and SMCs are described.

2. Homogenization Technique

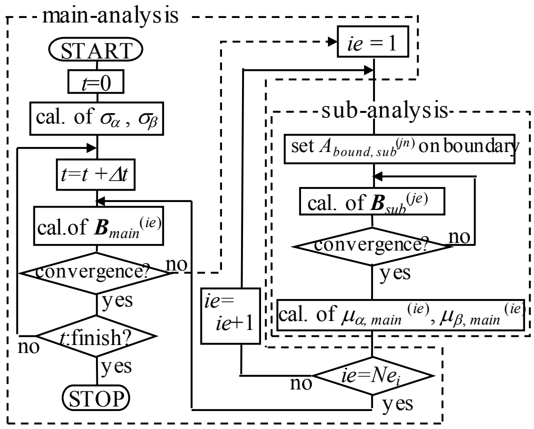
The flowchart of the homogenization technique for laminated core or SMCs is shown in Fig. 1. The sub-analysis with the cell model of a steel plate or particle is carried out for each element *ie* in the core at each nonlinear iteration in the 3D nonlinear eddy current analysis with the solid core model ("main-analysis"). In the sub-analysis, the flux densities obtained from the main analysis are given and the effective permeability used in the main analysis is calculated taking account of the nonlinearity, the eddy currents, and the gaps.

3. Laminated Core

In the sub-analysis of the homogenization technique for the laminated core, one sheet of steel plate with the gap is chosen as the cell model, shown in Fig. 2, and the 1D nonlinear eddy current analysis is carried out.

The homogenization technique is applied to a simple reactor model [3)] shown in Fig. 3. The cores with gaps are constructed by laminated steel plates (35A270) in the *z*-direction, and the space factor *F* is 0.95.

The flux distributions in the leg in the *y*-*z* plane obtained from the ordinary method, neglecting the eddy currents in the steel plates and gaps between the steel plates, and the proposed method mentioned above are shown in Fig. 4. The flux distribution obtained from the ordinary method is almost uniform in the core, whereas the flux densities in the upper layers of the core are larger than those in the other lower layers in the proposed method. This is because the flux concentrates at the corners of cores due to the gaps between cores and the larger flux in the upper layers remains due to the gaps between the steel plates. Therefore, the proposed method should be used for the accurate



Ne_i : number of elements in core in main-analysis

Fig. 1 Flowchart of homogenization technique.

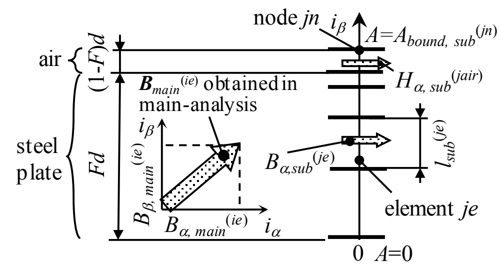


Fig. 2 1D cell model of a steel plate in laminated core.

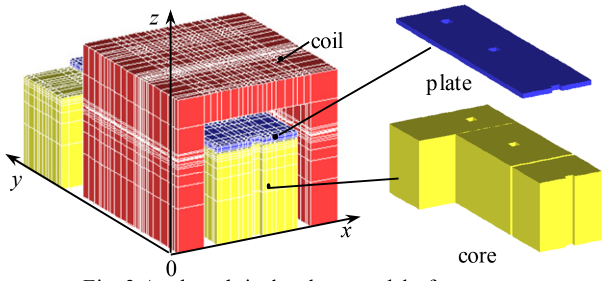
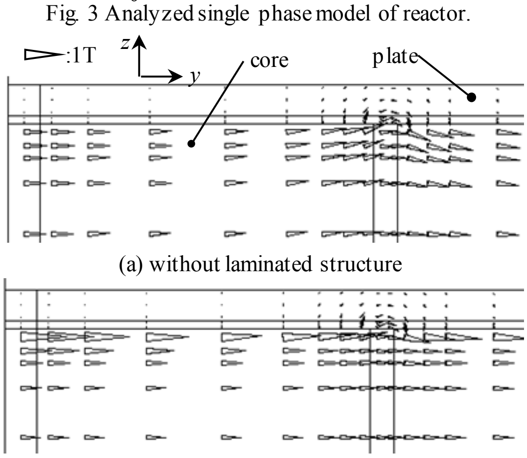


Fig. 3 Analyzed single phase model of reactor.



(a) without laminated structure

(b) with laminated structure

Fig. 4 Flux distributions in the leg.

analysis of the laminated core.

4. Soft Magnetic Composites (SMCs)

To establish the homogenization technique for SMC, the accurate cell model of a particle with gap is investigated[4]. Fig. 5 shows a 3D cell model for an actual SMC (MBS-R3, DIAMET CORPORATION). In this model, the particles are assumed to be square shape and be formed regularly and infinitely. Two configurations of particles with uniform and un-uniform gaps are examined as shown in Fig. 5 (a) and (b), respectively. In the model with the uniform gap, two gap lengths G_0s are selected. One is G_0s = 1.37 μm determined by volume filling rate. The other is set to be G_0 = 0.35 μm so that the calculated magnetic field H_z coincides with measured one at B_z = 1T. In the non-uniform gap model, G_1, G_2, and L in Fig 1 (b) are optimized to be 0.15, 1.0, and 35 μm so that the calculated BH curve coincides with the measured one as possible.

Fig. 6 shows the calculated and measured effective initial BH curves in the low frequency in which the eddy current can be neglected. In the model with uniform gap G_0 = 1.37 μm, the calculated effective permeability is much smaller than the measured one because the gap length determined by the filling ratio is larger than most of those in the actual SMC due to its complex shape of particles. The model with the smaller uniform gap G_0 = 0.35 μm cannot represent the measured BH curve completely, too. The BH curve obtained by the optimized model with non-uniform gap is good agreement with the measured one. It can be concluded that the cell model with non-uniform gap should be used for the homogenization technique of SMC.

Fig. 7 shows the comparison of the calculated iron losses obtained by using the cell model shown in Fig. 5 (a) with the measred ones. The calculated hysteresis losses are in good agreement with the measured ones because the applied flux density coincides with each other. However, the eddy current losses are different from measured ones because the insulation between particles are not completed in an actual SMCs. This problem will be investigated in future.

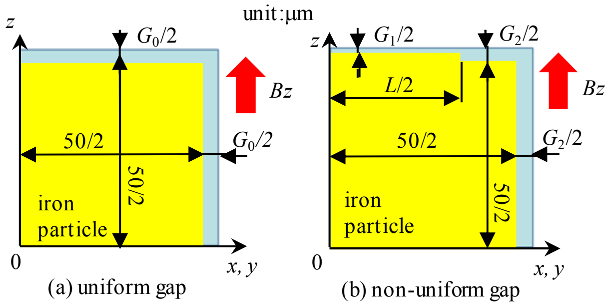


Fig. 5 3D Cell model of a particle in SMC.

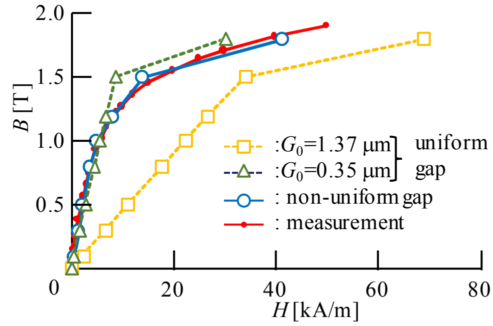


Fig. 6 Calculated and measured initial BH curves.

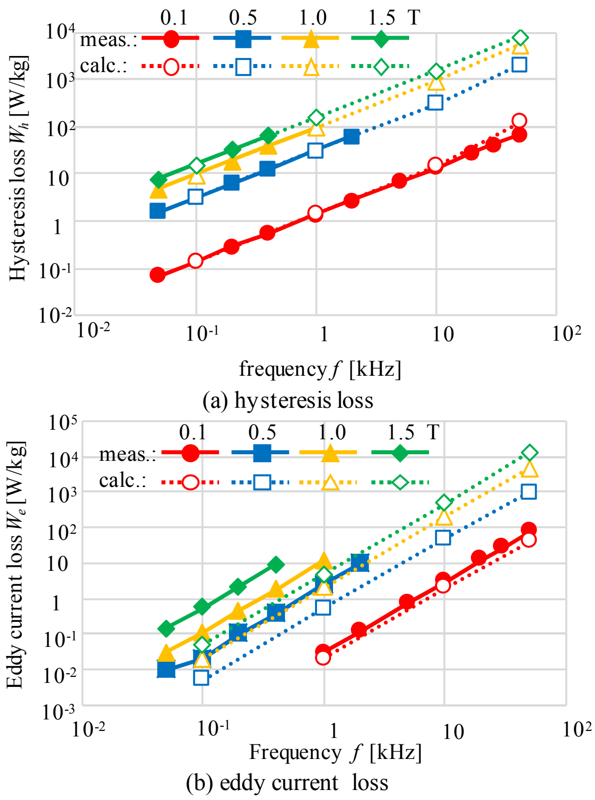


Fig. 7 Iron losses.

References

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4) Y. Gao, et al., *IEEE Trans. Magn.*, vol. 54, no. 3, Art. no. 7401504, 2018.