Modeling of Anisotropic Laminated Magnetic Cores using Homogenization Approaches

Johannes Ziske[1], Holger Neubert[*1], Rolf Disselnkötter[2]

[1] Technische Universität Dresden, Institute of Electromechanical and Electronic Design, Germany
[2] ABB AG, Corporate Research Center Germany, Ladenburg, Germany

[*] Corresponding author: D-01069 Dresden, Germany,
holger.neubert@tu-dresden.de

COMSOL CONFERENCE
2014 CAMBRIDGE

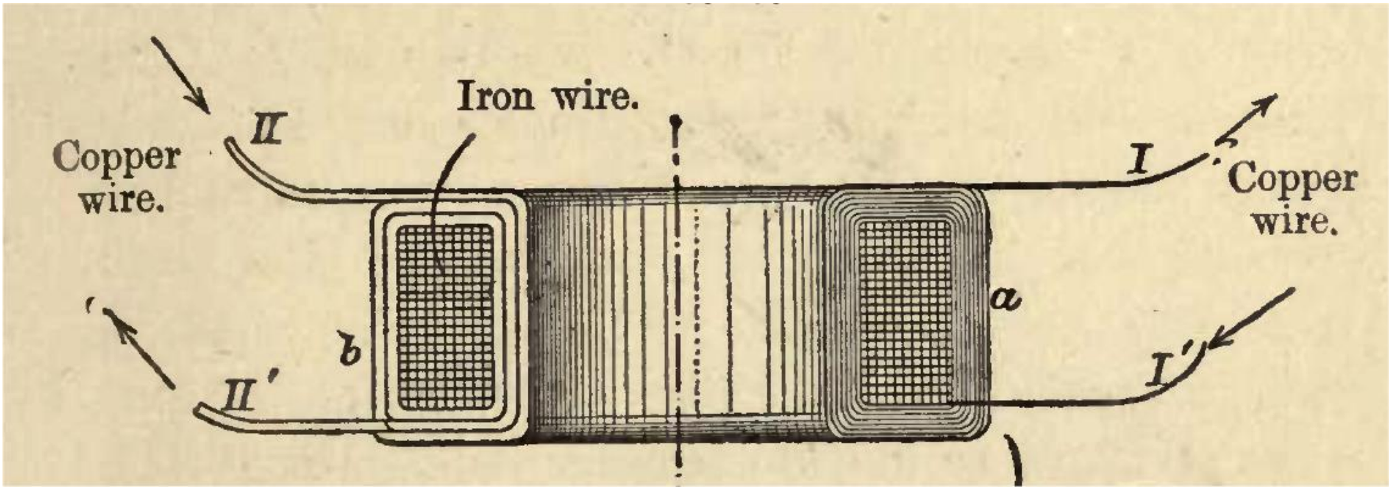
Outline

1 Introduction

Laminated magnetic cores

- Used to reduce eddy currents
- Sheet thickness *d* ≪ Core thickness

$$d < 2\delta = \frac{1}{\sqrt{\pi f \sigma \mu}}$$

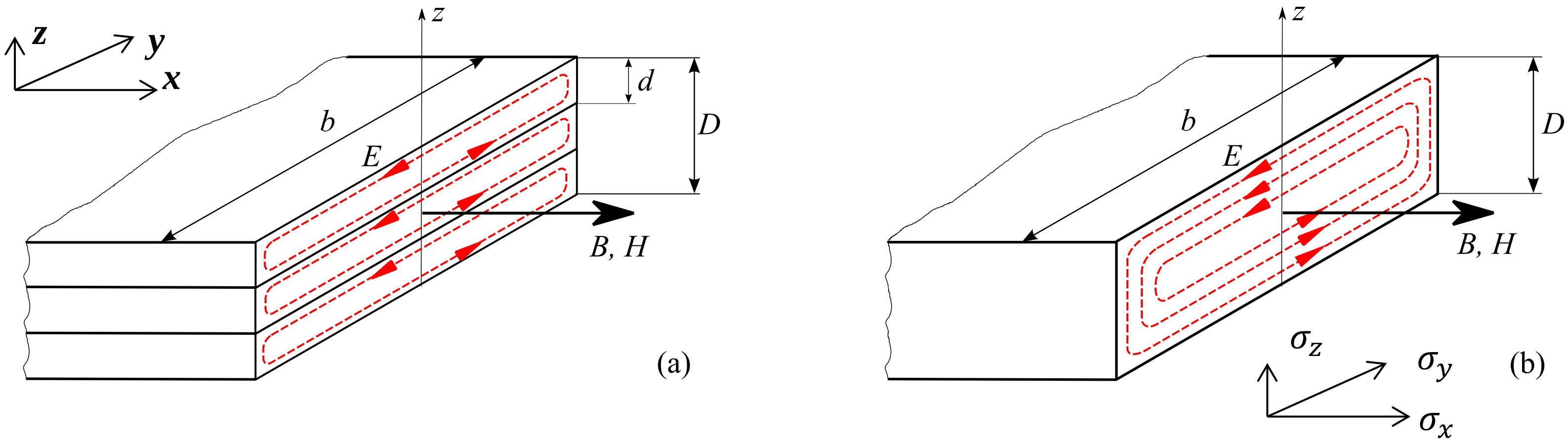


Zipernowsky, Déri, Bláthy, 1885
[F. Uppenborn: History of the transformer 1889]

2 Homogenization Procedures

Principle

- Replacing the laminated structure (a) by a single domain of an electrically orthotropic material (b) which exhibits the same macroscopic behavior
- Computational effort can be significantly reduced



2 Homogenization Procedures

- Several approaches published, e.g. [1 - 5]
- Orthotropic electrical and magnetic material characteristics assumed

	$[\sigma] = \begin{bmatrix} \sigma_x & & \\ & \sigma_y & \\ & & \sigma_z \end{bmatrix}$	$[\mu] = \begin{bmatrix} \mu_x & & \\ & \mu_y & \\ & & \mu_z \end{bmatrix}$
KIWITT [2]	$\sigma_x = \sigma_y = \frac{1}{n^2}\sigma_b$ $\sigma_z = \sigma_b$	$\mu_x = \mu_y = F\mu_b$
WANG [3]	$\sigma_x = \sigma_y = \sigma_b$ $\sigma_z = \left(\frac{d}{b}\right)^2 \sigma_b$	$\mu_x = \mu_y = F\mu_b$ $\mu_z = \frac{1}{\frac{F}{\mu_b} + \frac{1-F}{\mu_0}}$

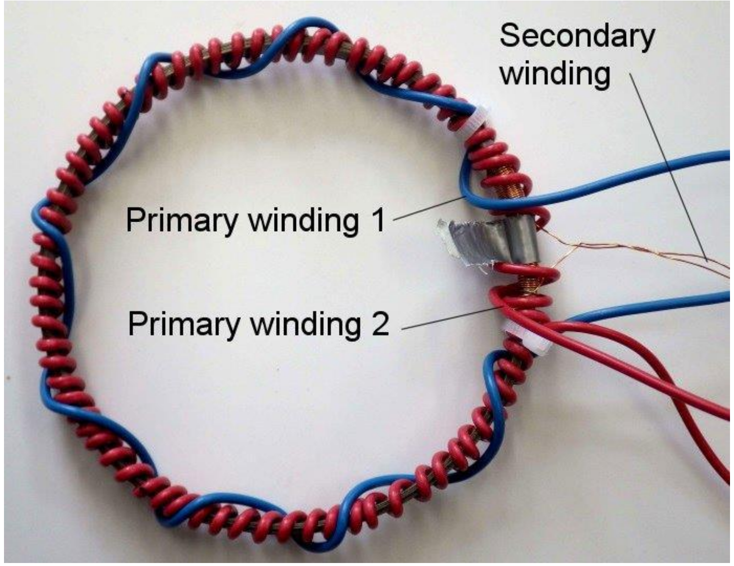
σ_b *isotropic conductivity of the bulk material,*
n *number of stacked sheets*

[1] V Silva, G Meunier, A Foggia, IEEE Trans. on Magn. 31 2139-2141 (1995)
[2] JE Kiwitt, A Huber, K Reiß, Electrical Engineering (Archiv für Elektrotechnik) 81 369-374 (1999)
[3] J Wang, SL Ho, W Fu, Ch T Kit, M Sun, IEEE Trans. on Magn. 47 1378 -1381 (2011)
[4] P Hahne, R Dietz, B Rieth, T Weiland., IEEE Trans. on Magn. 32 1184-1187 (1996)
[5] A Kühner, Diss. Univ. Fridericiana Karlsruhe, Fakultät für Elektrotechnik (1999)

3 Transient Electromagnetic Inductor Model

Investigated Transformer Cores

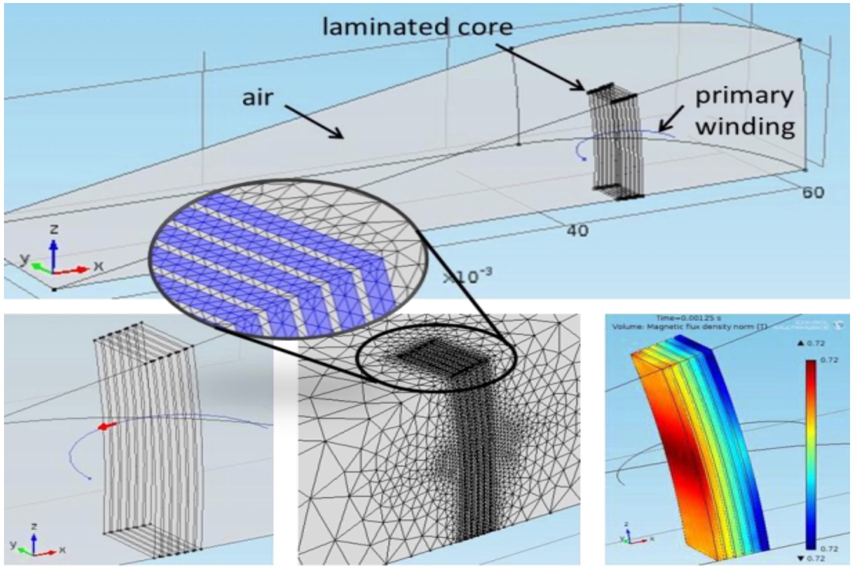
- *Permalloy* tape wound core
- Core sheet thickness 250 µm, 5 sheets (helically wound)
- Core width 6 mm, mean length of the flux path 284 mm
- Secondary coil is closely wound directly on the core (65 windings)
- Primary coil is equally distributed over the ring (9 / 74 windings)



3 Transient Electromagnetic Inductor Model

Finite Element Model

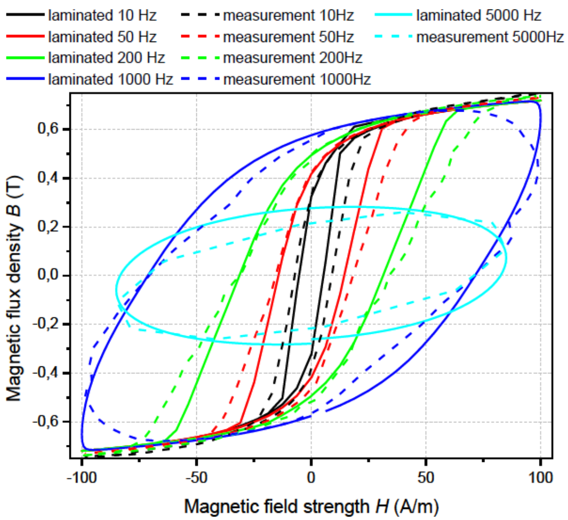
- Parametric 3D geometry, advantage of $\frac{1}{2} \cdot {}^{1}/_{32}$ symmetry
- Core as sheets with insulating layers between or as solid
- *mf* mode used for the transformer model, time-dependent study
- Current on a circular edge around the core, sinusoidal excitation current

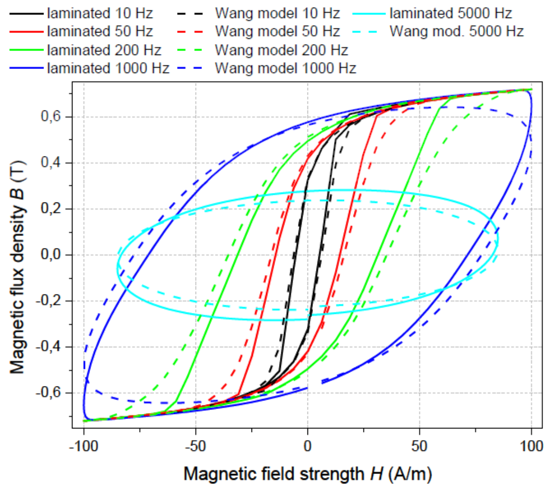


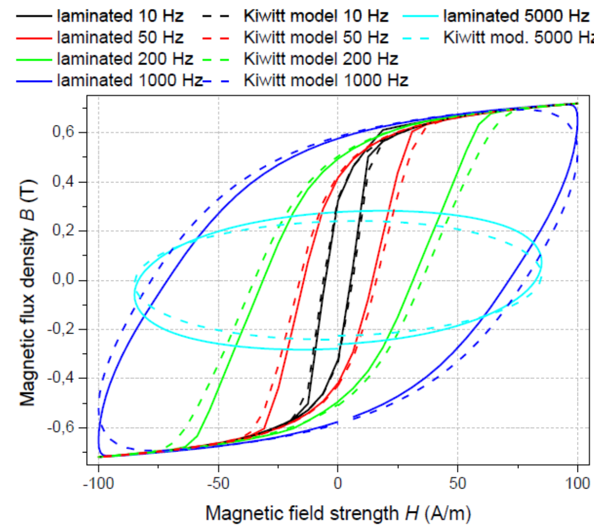
4 Measurement and Simulation Results

Dynamic hysteresis loops

- Magnetic flux density and lamination plane in parallel
- Measured data vs. simulation results from models with explicitely modeled core structure vs. models with homogenized core



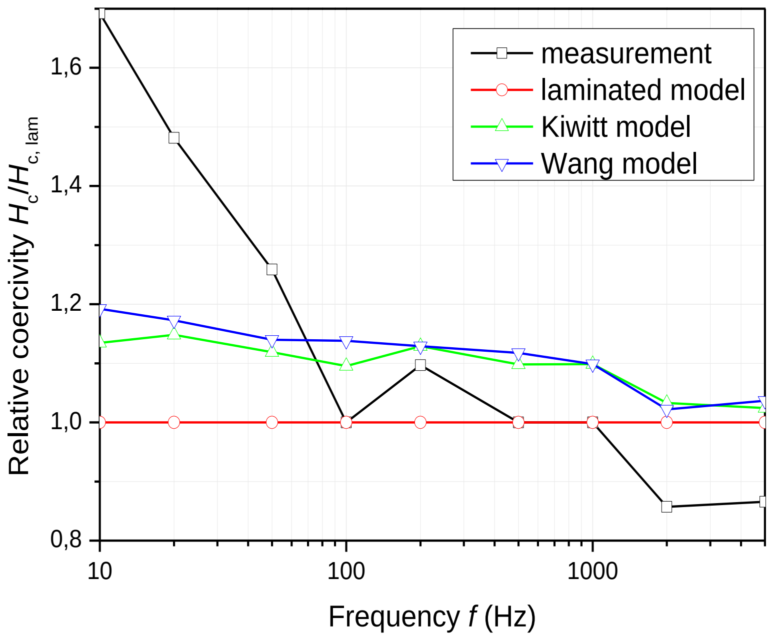


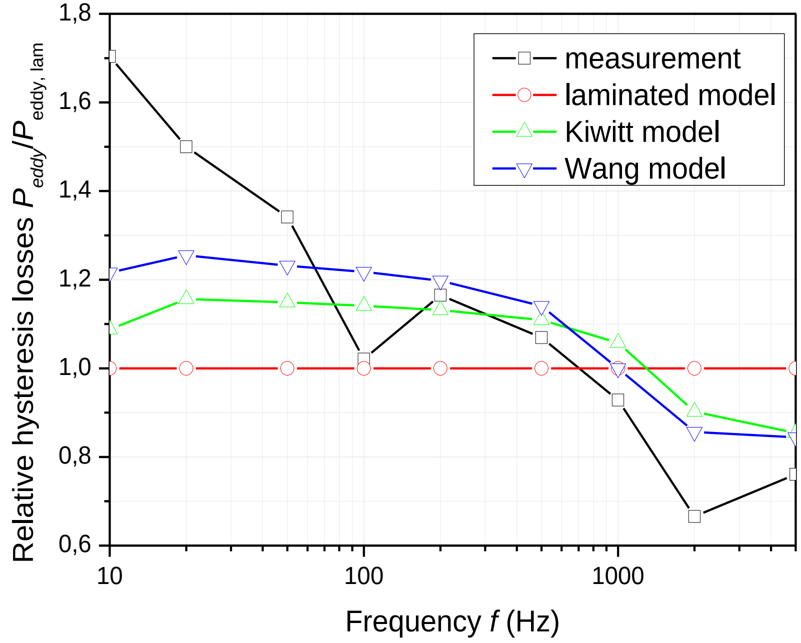


4 Measurement and Simulation Results

Dynamic hysteresis loops

- Coercivity
- Dynamic hysteresis losses

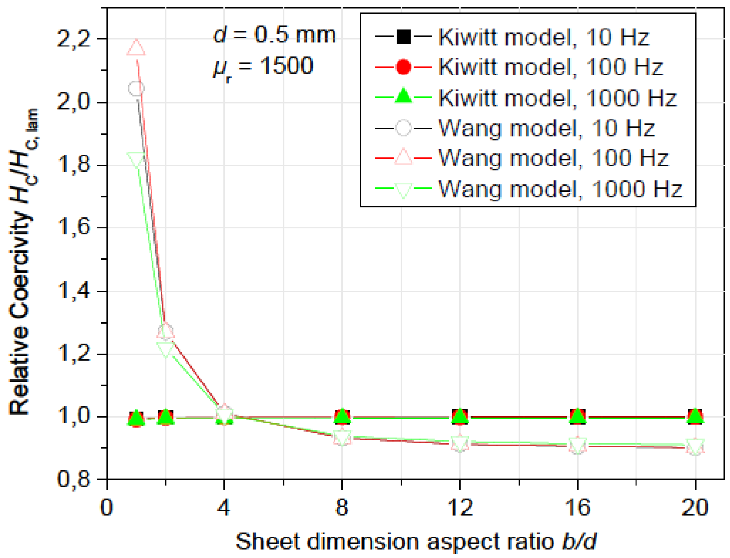


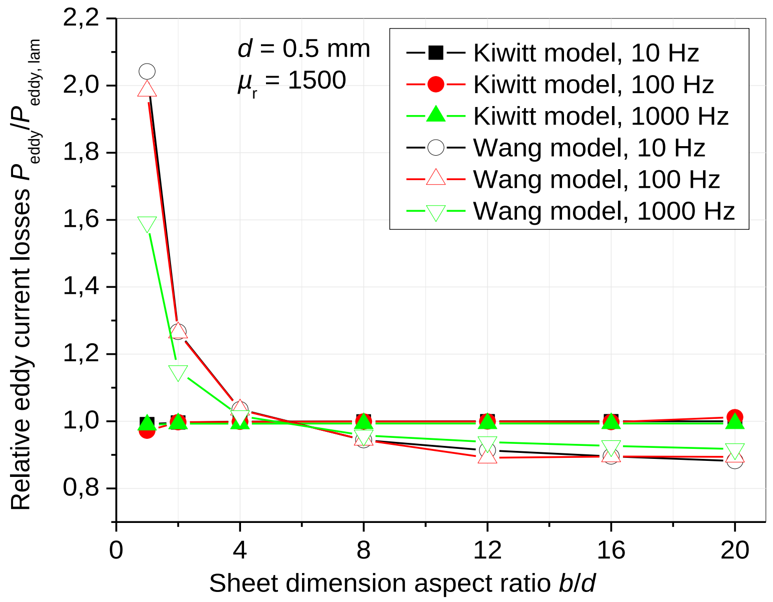


4 Measurement and Simulation Results

Dynamic hysteresis loops

- Influence of width-to-thickness ratio of the sheets
- Simulated for linear magnetic core material
- Explicitly modeled core structure vs. homogenized core

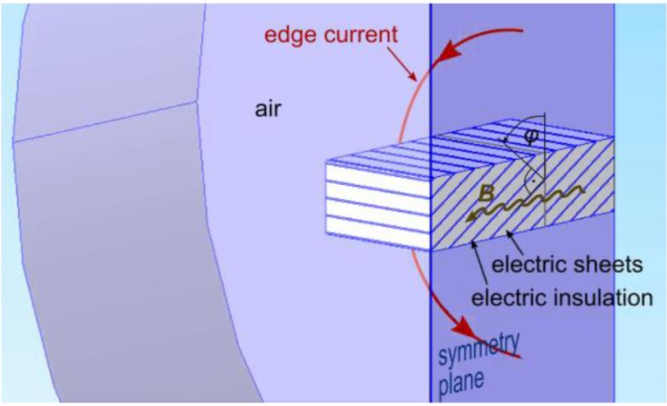


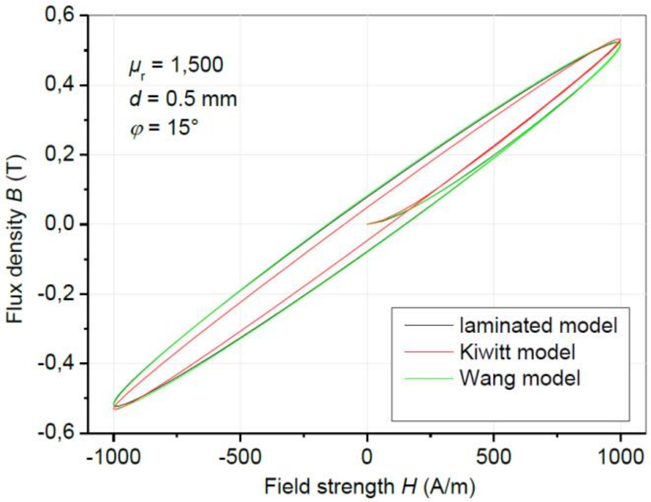


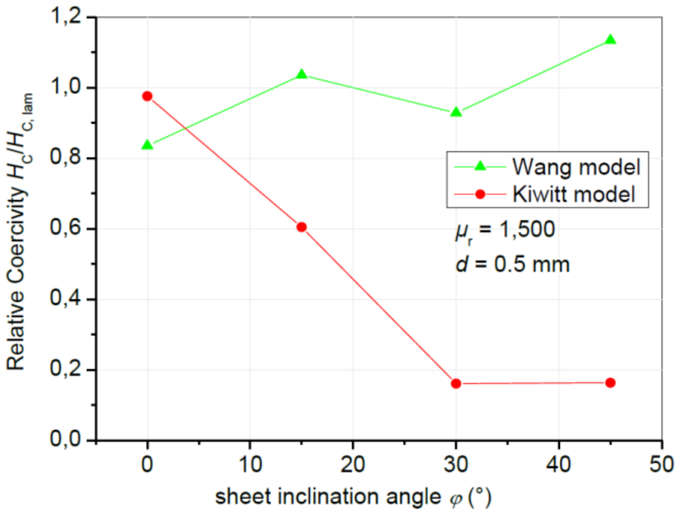
5 Measurement and Simulation Results

Dynamic hysteresis loops

- Magnetic flux density and lamination plane inclined







5 Conclusions

- Homogenization approaches for laminated magnetic cores are easy to use
- Significant reduction of DoF compared to models with explicit core structure
- Simulation results were compared both to those found on explicitely modeled laminations and to experimental results
- The KIWITT homogenization approach
  - fits best the results from models with laminated cores provided that the magnetic flux is in parallel to the sheets
  - reliable within large ranges of frequency and width-to-thickness ratio
  - underestimates dynamic hysteresis effect for inclination angles between flux and lamination plane
- The WANG model
  - underestimates slightly both the coercivity and the dynamic losses
  - is applicable for sheets with an width-to-thickness ratio > 4
  - is robust against inclinations between flux and lamination plane
- Other models show larger deviations

Thank you very much for your attention.