technische universität dortmund

Institute of Forming Technology and Lightweight Components

Analytical-based modeling for electromagnetic sheet metal forming with multi-turn coils

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13.10.2021

ICHSF21 INTERNATIONAL CONFERENCE ON HIGH SPEED FORMING

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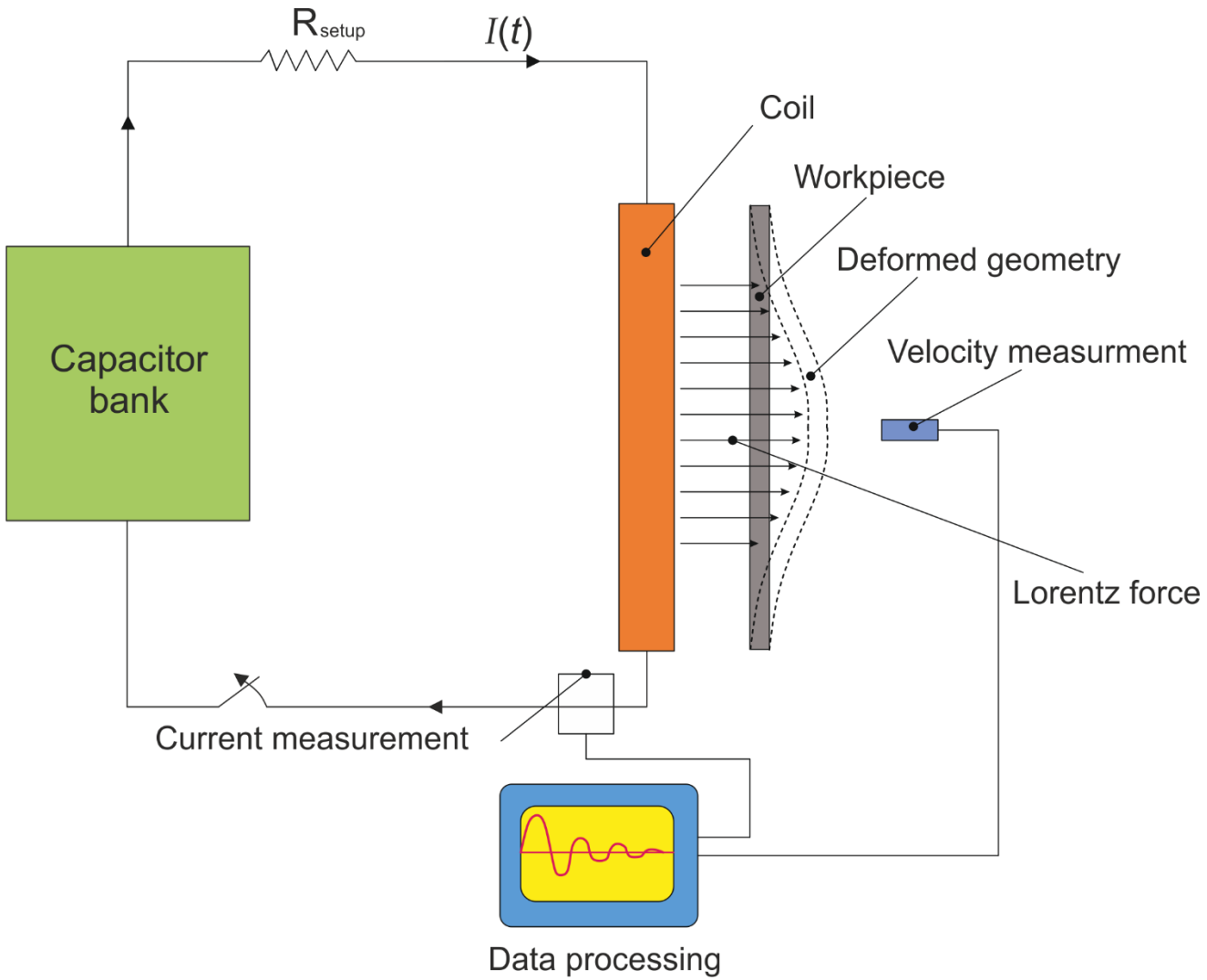
State of the art



Electromagnetic forming (EMU) of sheet metal

Research areas

- Prediction of the workpiece geometry after the forming process
- Design of the coil (tool) to increase tool life
- Optimization of different process parameters

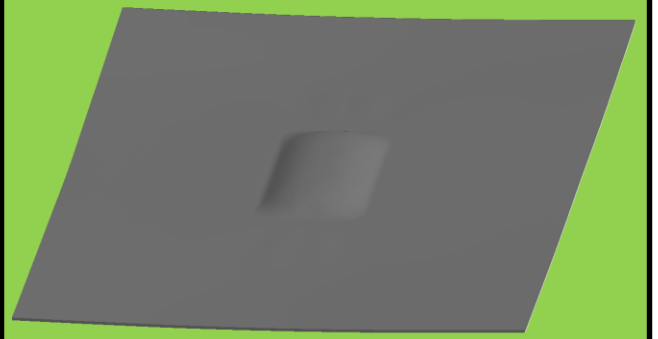
Contents

Disadvantages of the current numerical approach (LS-Dyna/FEM+BEM)

Input

- Current curve
- Boundary conditions
- Material data

Objective



Formed part

Thermo-mechanical electromagnetic model

Technical questions

- Coil geometry
- Meshing
- Current amplitude/ frequency
- Simulation parameters

Problems

- Long solution times
- Inflexible setup
- No symmetry
- Not open source/ Expensive

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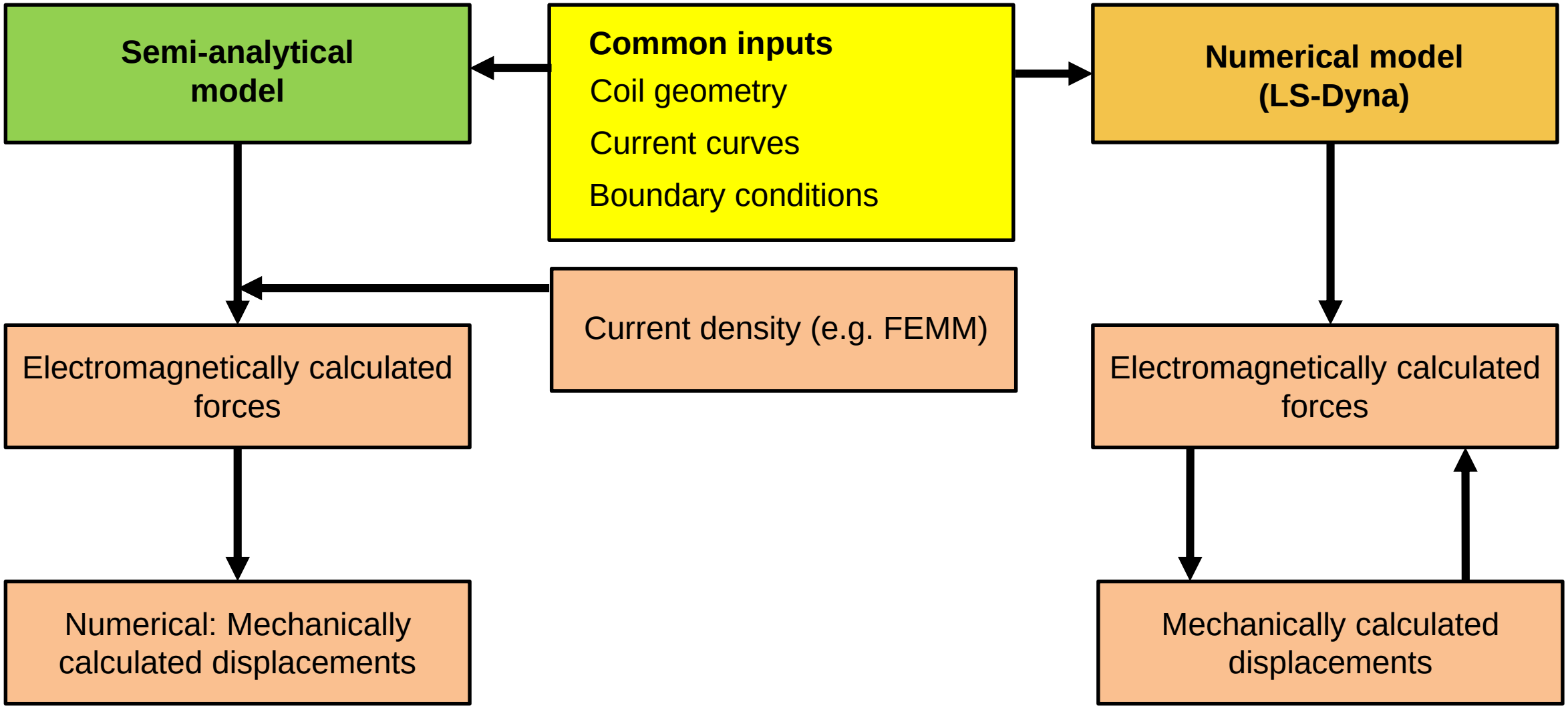
Objective


Semi-analytical model
Common inputs
Coil geometry
Current curves
Boundary conditions
Numerical model (LS-Dyna)
Current density (e.g. FEMM)
Electromagnetically calculated forces
Electromagnetically calculated forces
Numerical: Mechanically calculated displacements
Mechanically calculated displacements

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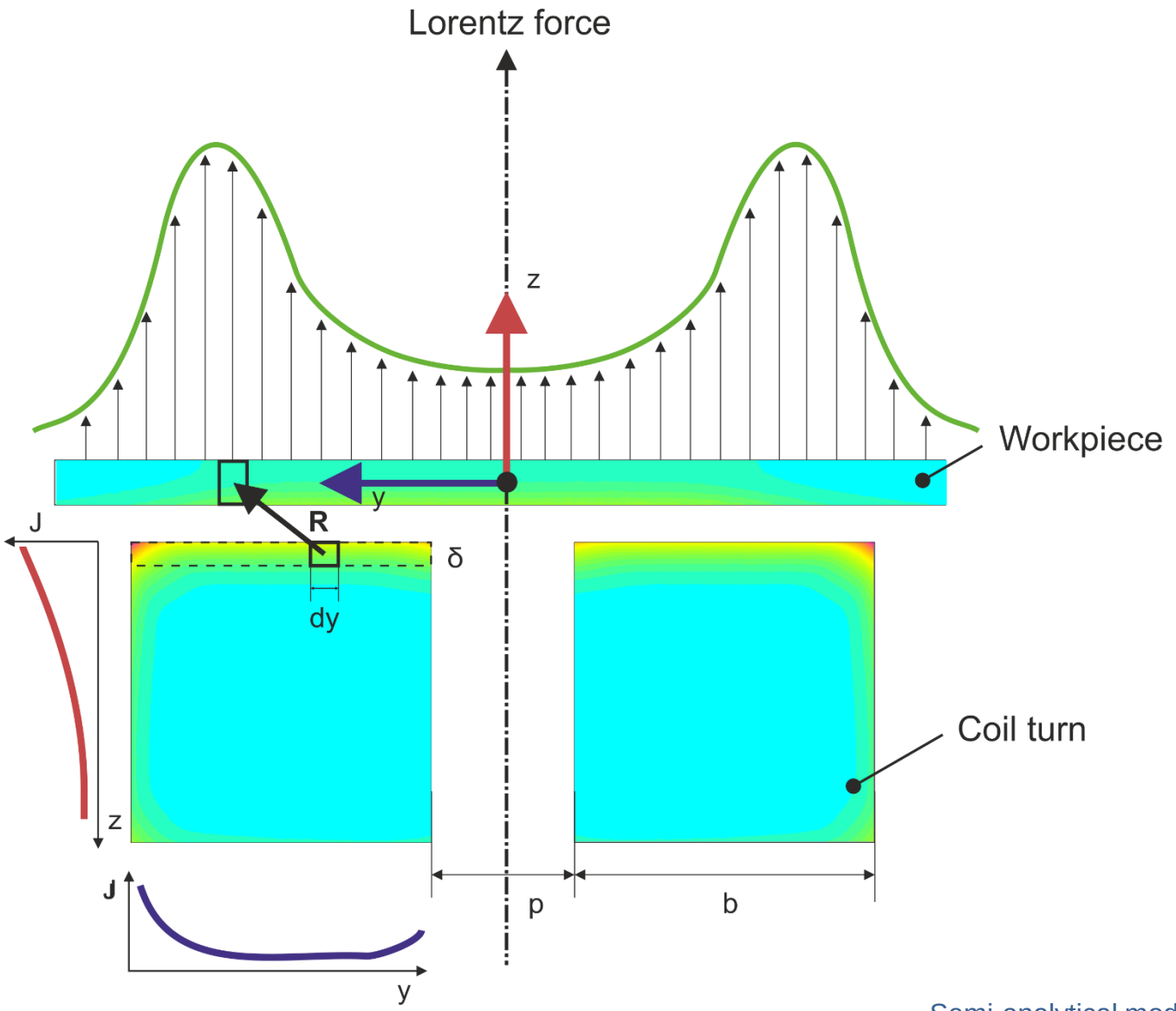
- Introduction
- Objective
- Semi-analytical model
  - Development
  - Validation
- Conclusion

Assumptions of the model



Assumptions

- No displacement of the workpiece
- All current flows in the upper layer
- Current density variation only in y-direction - *J*(y)
- No temperature changes

Semi-analytical model

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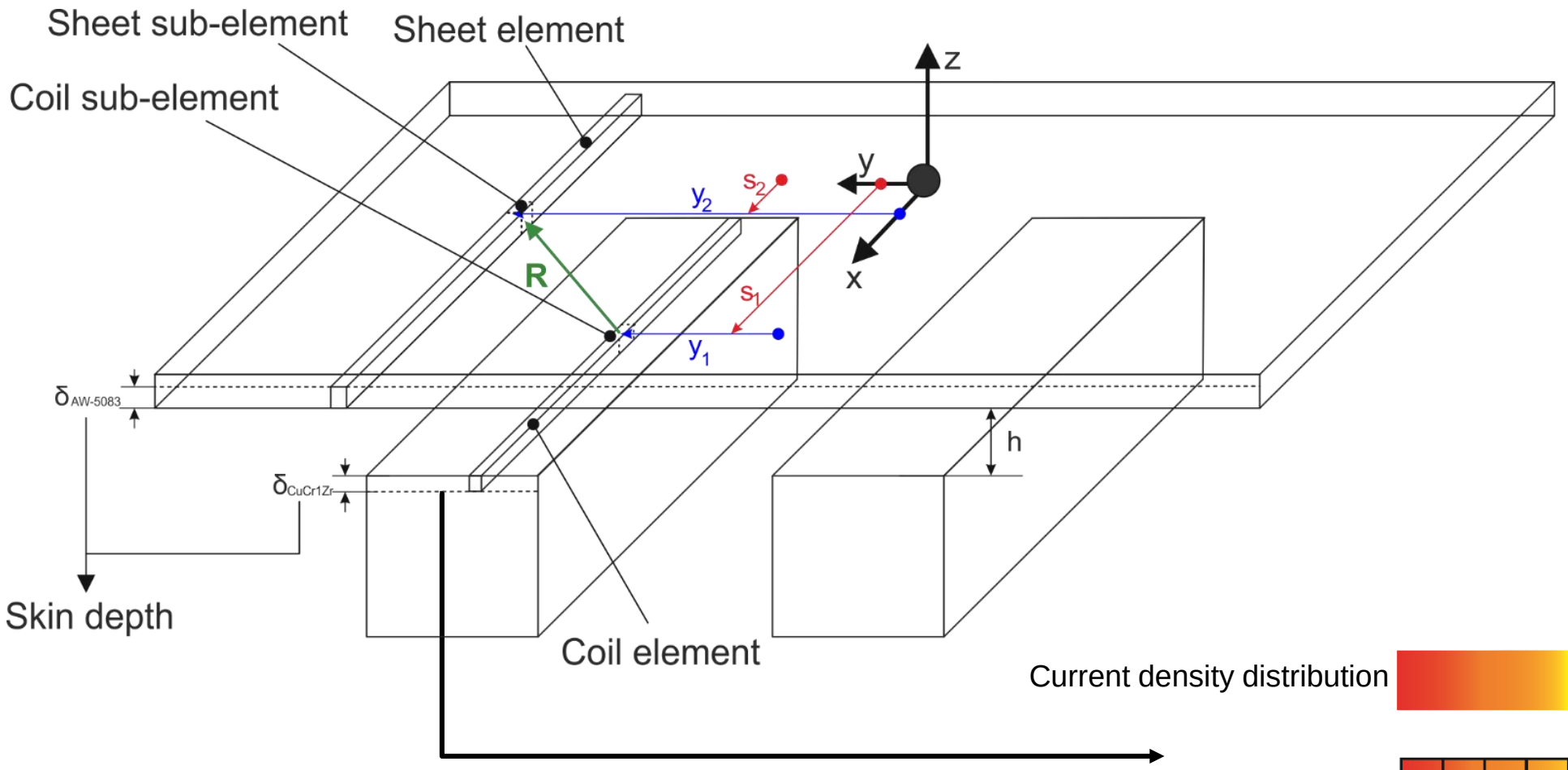
Structure of the model



Current density

Max.

Min.

Current density distribution

Discretization

Semi-analytical model

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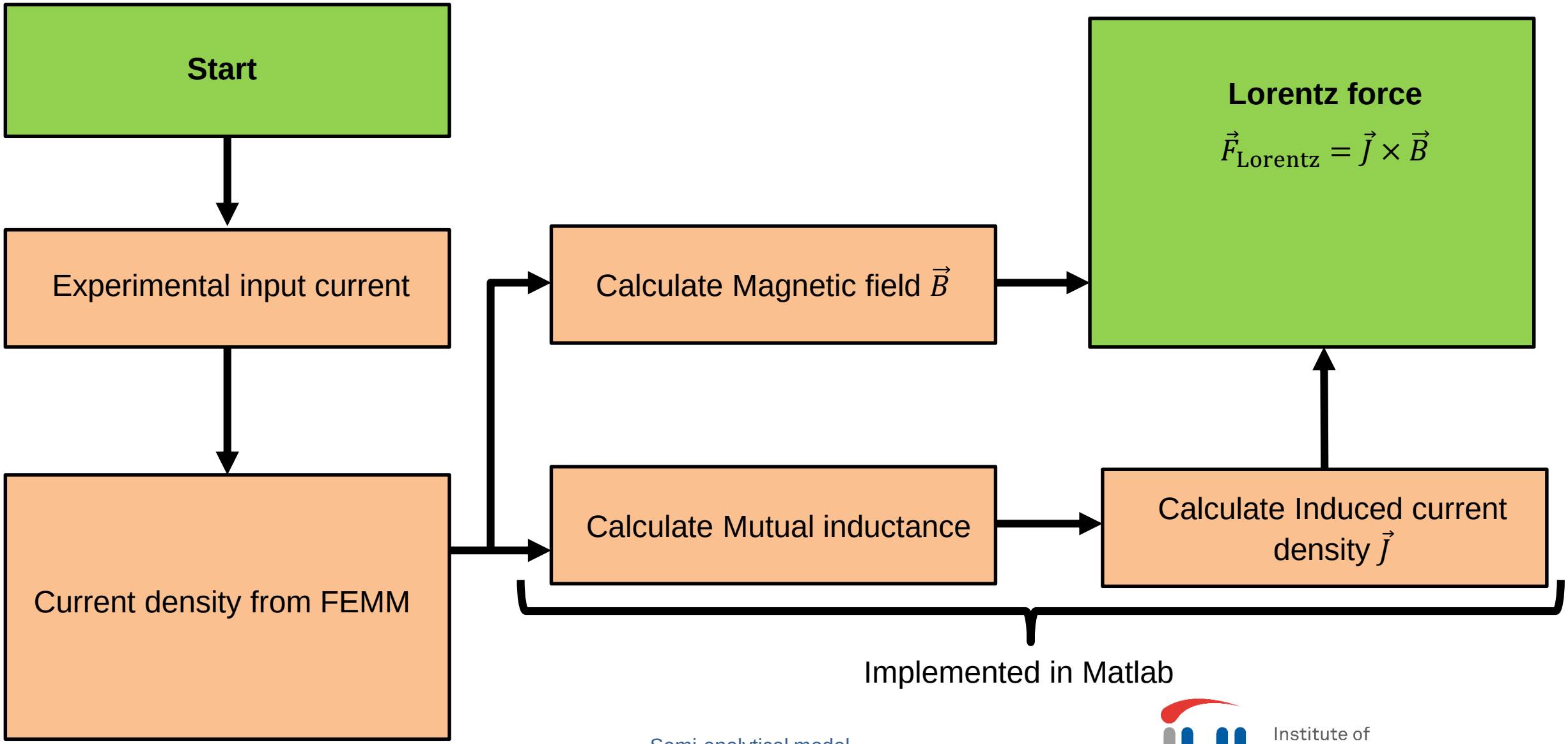
Semi-analytical calculation procedure



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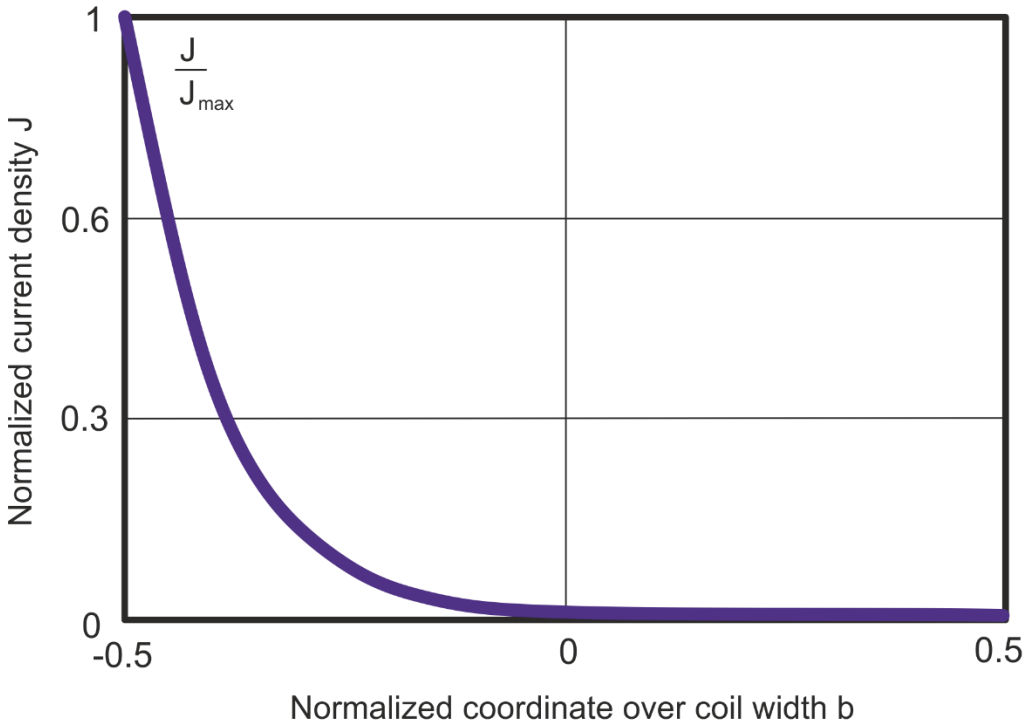
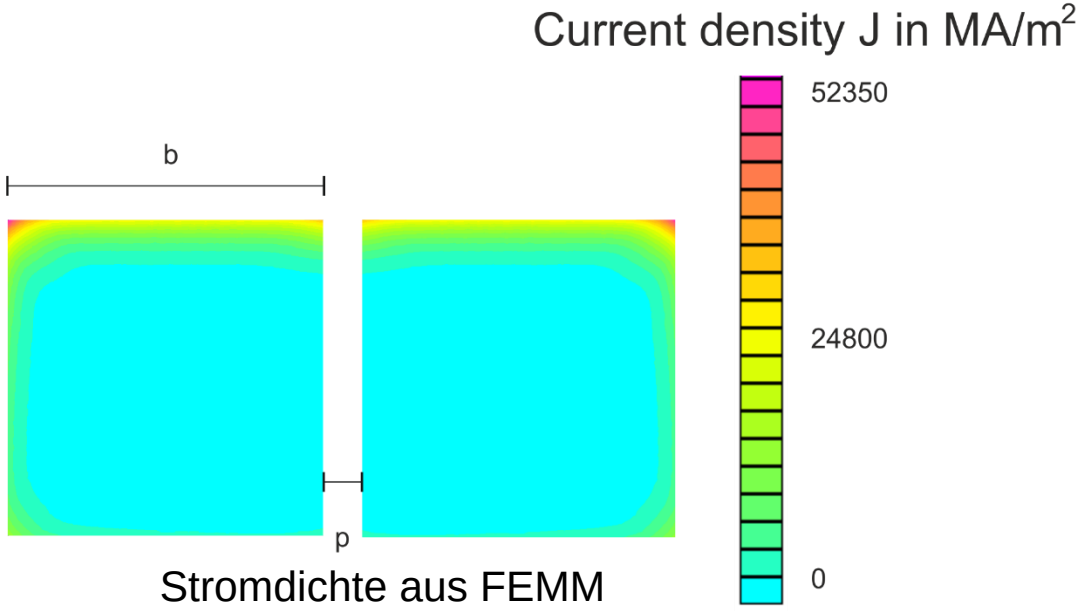
Current density distribution in the coil

Influencing parameters

- Distance between coil turns (p)
- Skin effect
- Electrical conductivity
- Shape of the cross section



Source: Adelbagi, 2007



Stromdichte aus FEMM

- Previous analytical models ignore the proximity effect
- Only for very simple cross sections (rectangular, circular)

Semi-analytical model

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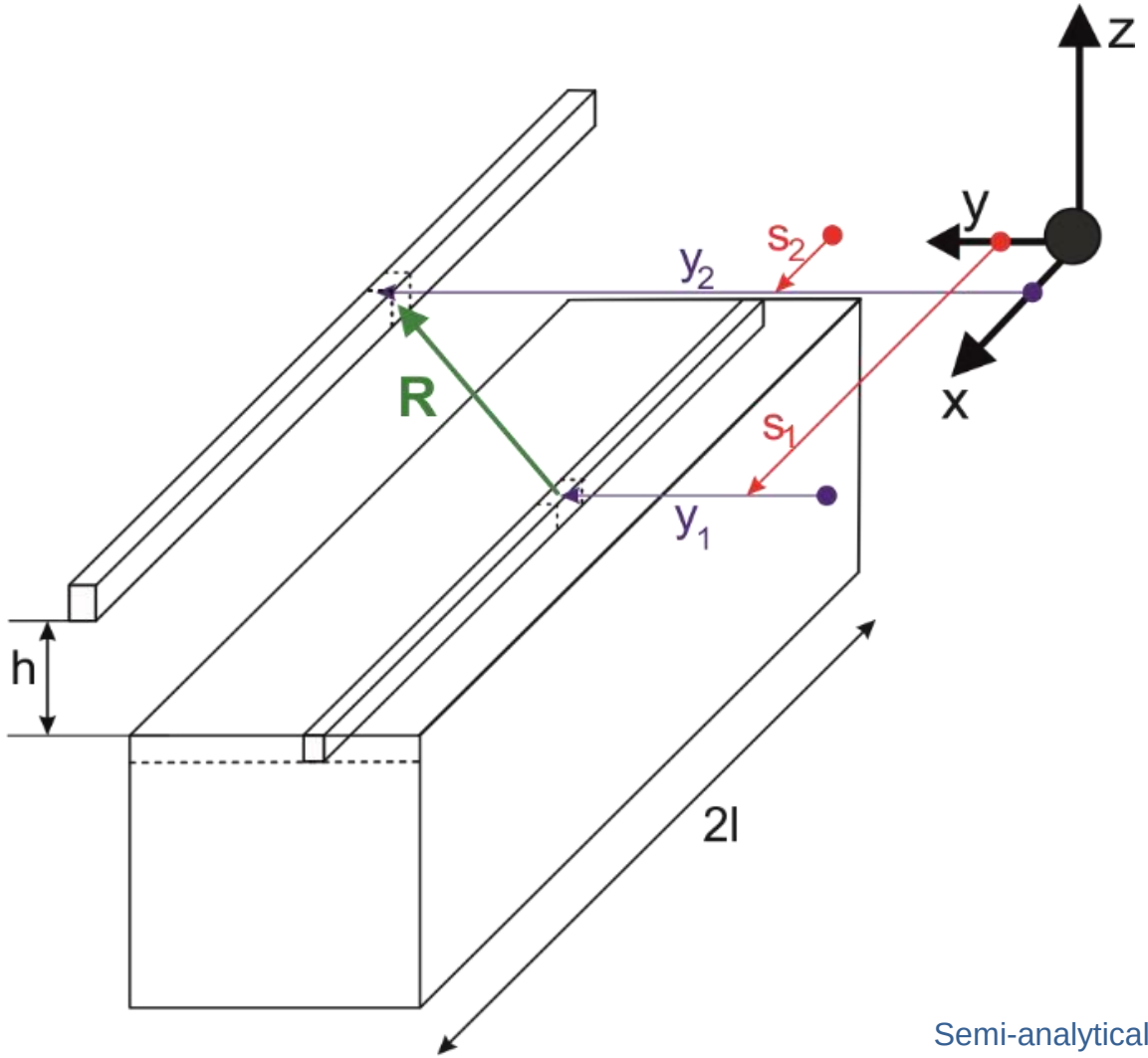
Mutual Inductance

Interaction between the magnetic field of two electrical conductors



$$L_{12} = \frac{\mu_0}{4\pi} \oint_{C_1} \oint_{C_2} \frac{\mathbf{ds}_1 . \mathbf{ds}_2}{R}$$

Here: $$L_{12} = \frac{\mu_0}{2\pi}\left[l \sinh^{-1}\left(\frac{l}{b}\right) + b - \sqrt{l^2 + b^2} \right]$$

$$b = \sqrt{(y_2 - y_1)^2 + h^2}$$

Induced Potential difference (V)

$$\mathrm{V} = -L_{12}\frac{dI_1}{dt}$$

Here, I_1 is the input current

Semi-analytical model

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Induction current

Induced current paths are known

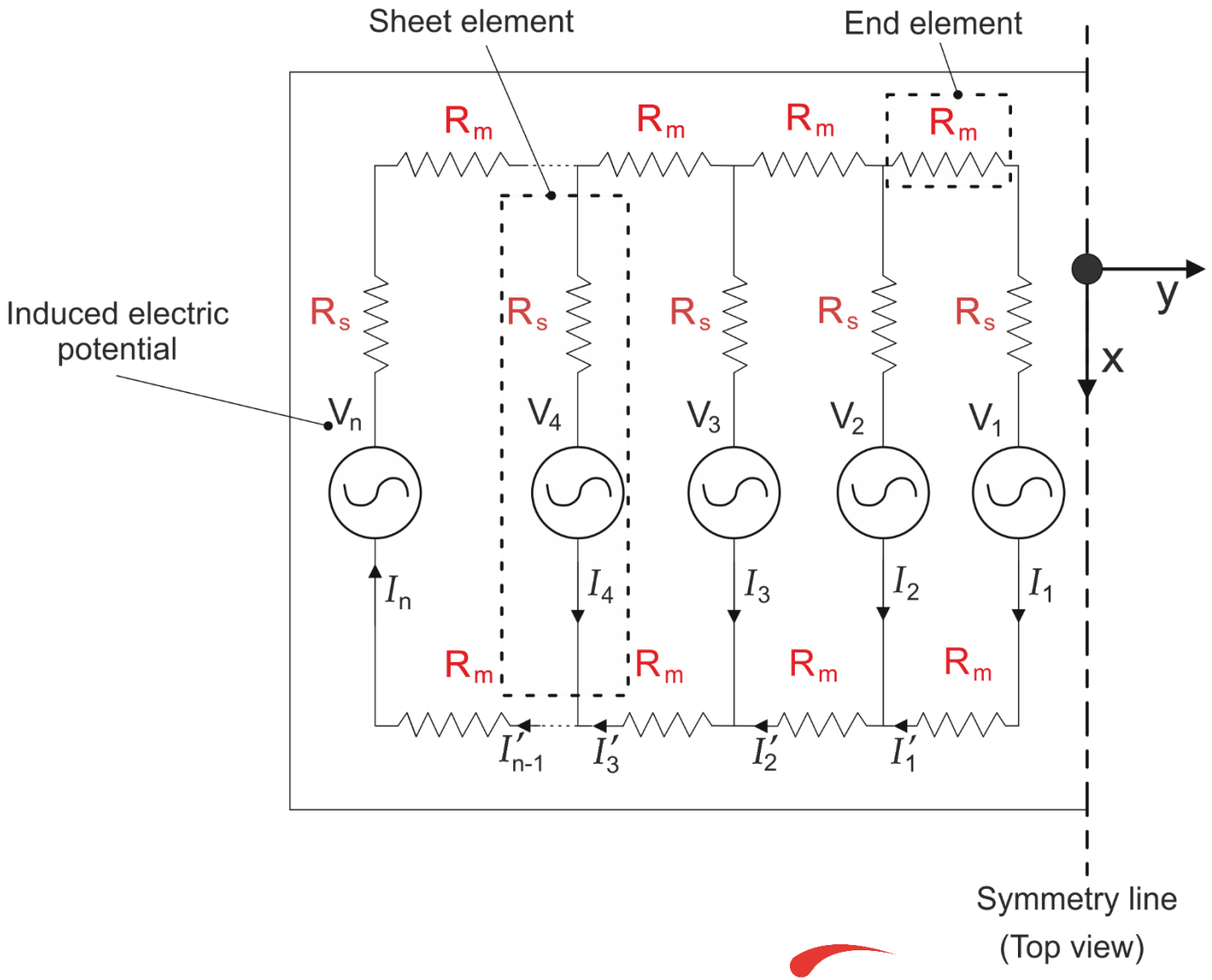
Resistance (R_e) of an element

$$R_e = \frac{l}{\sigma A}$$

l - Element length
A - Cross-sectional area of the element
σ - Electrical conductivity

From Ohm's law

$$[V_s] = [V] - R_s[I]$$



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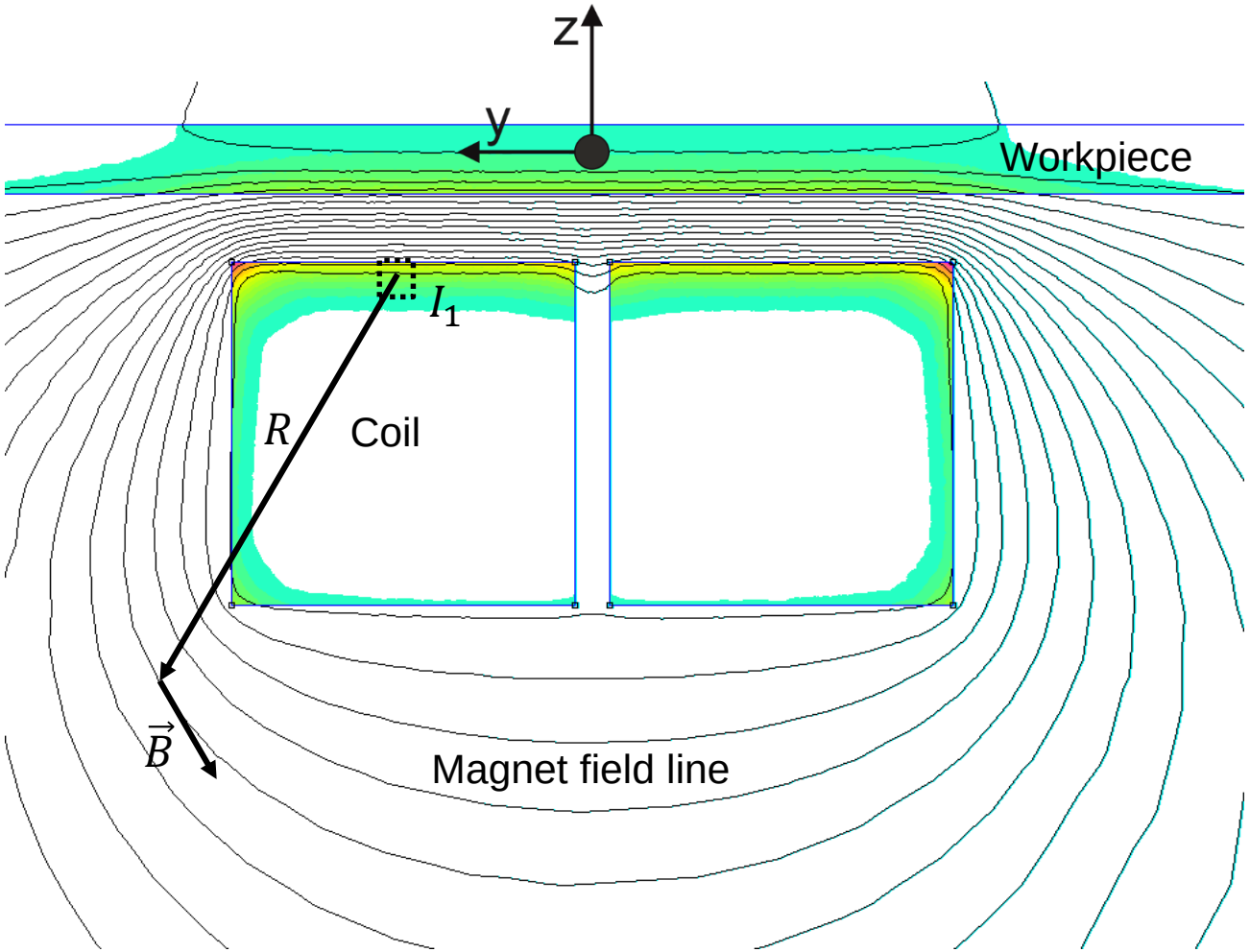
Magnetic field ($\vec{B}$)

Calculation based on the current with Biot-Savart's law



Biot-Savart's law

$$\vec{B} = \frac{\mu_0 I_1}{4\pi} \oint_{c_1} \frac{\mathbf{ds} \times \boldsymbol{R}}{R^3}$$

Here:

$$\overrightarrow{B_y} = \frac{\mu_0 I_1}{4\pi} \left[\frac{\frac{l}{2} - s_2}{b^3 \sqrt{\frac{\left(\frac{l}{2} - s_2\right)^2}{b^2} + 1}} \right] - \left[\frac{-\frac{l}{2} - s_2}{b^3 \sqrt{\frac{\left(-\frac{l}{2} - s_2\right)^2}{b^2} + 1}} \right]$$

Semi-analytical model

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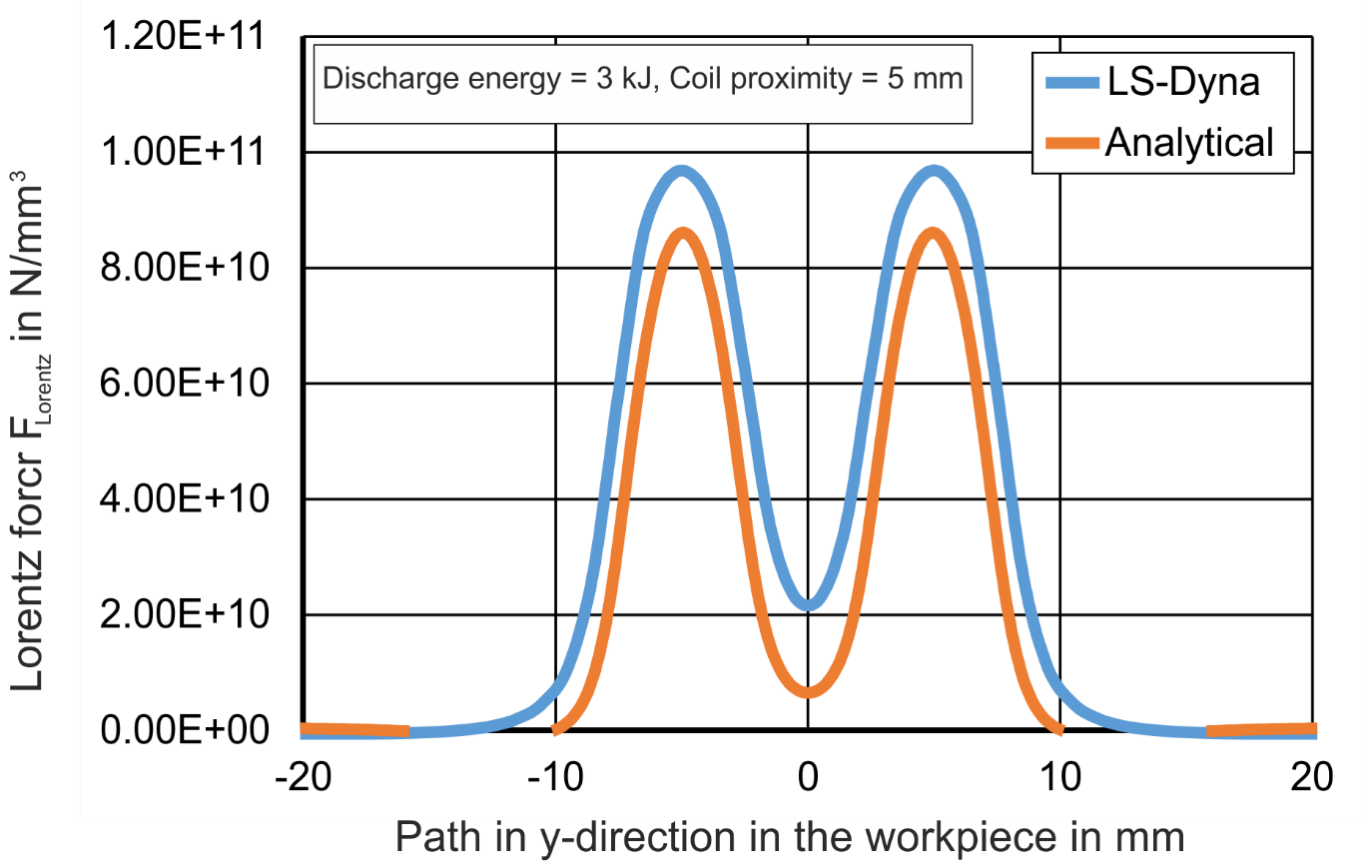
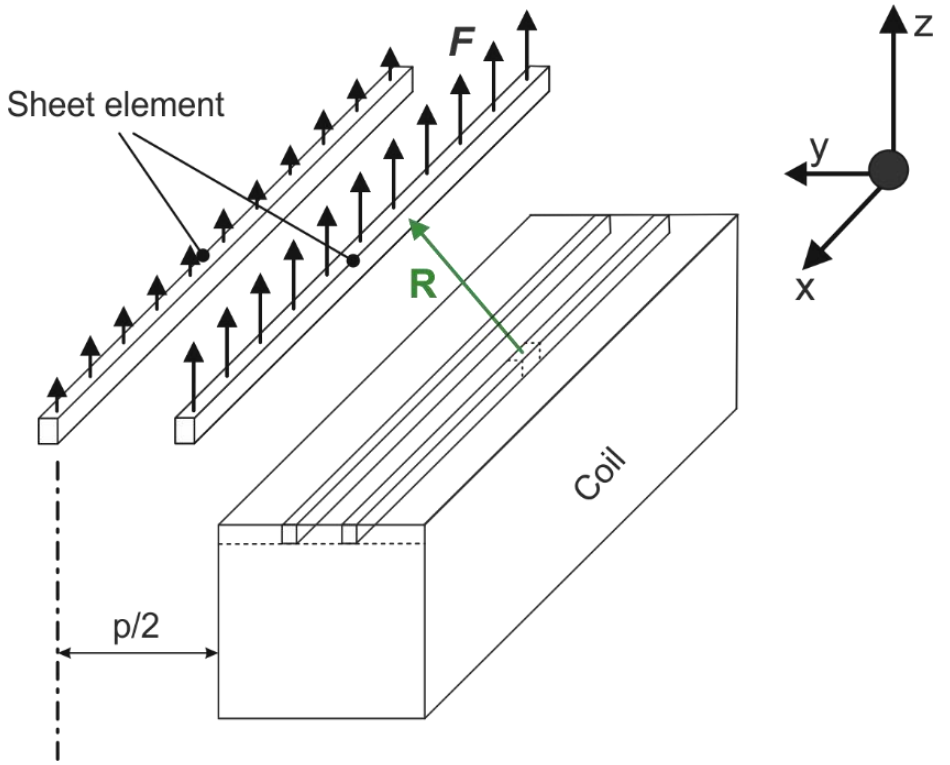
Results and validation

Lorentz force distribution in the workpiece

$$\vec{F}_{\text{Lorentz}} = \vec{J} \times \vec{B}$$





Time-dependent input current

$$I = I_0 e^{-\lambda t} \sin \omega t$$

Time dependent force

$$F = F_0 e^{-2\lambda t} \sin^2 \omega t$$

Semi-analytical model

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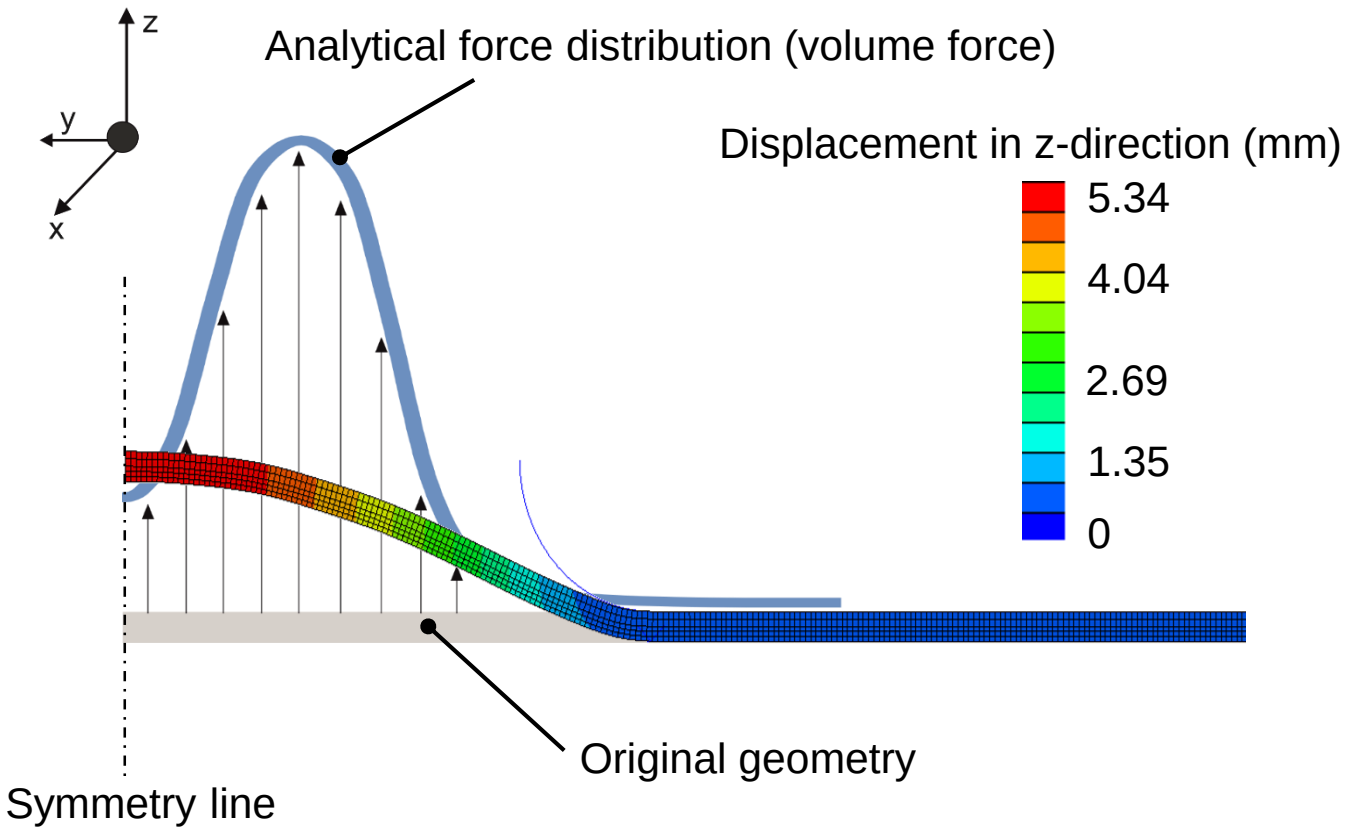
Results and validation

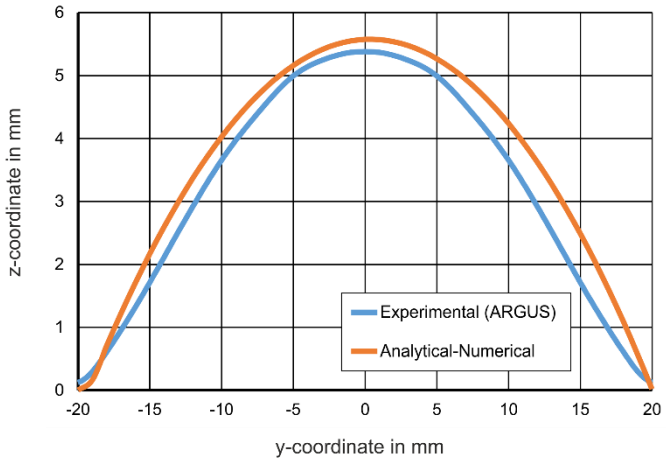
Simulation for validation in ABAQUS

Discharge energy = 3 kJ, Coil proximity = 5 mm

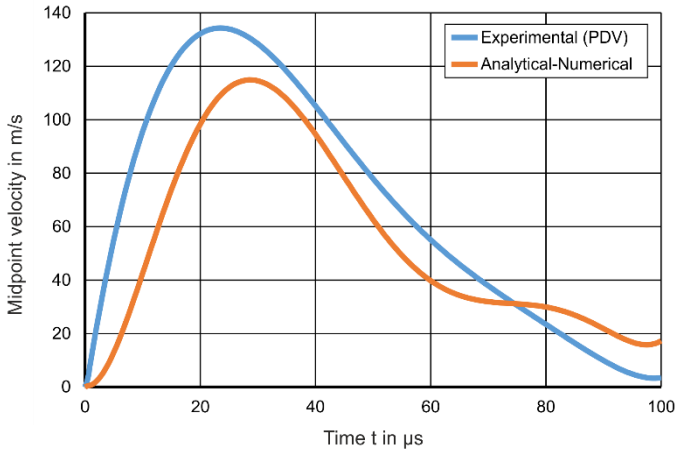


Quelle: Kabirian et al., 2014

Comparison of the final workpiece geometries



Comparison of midpoint velocities



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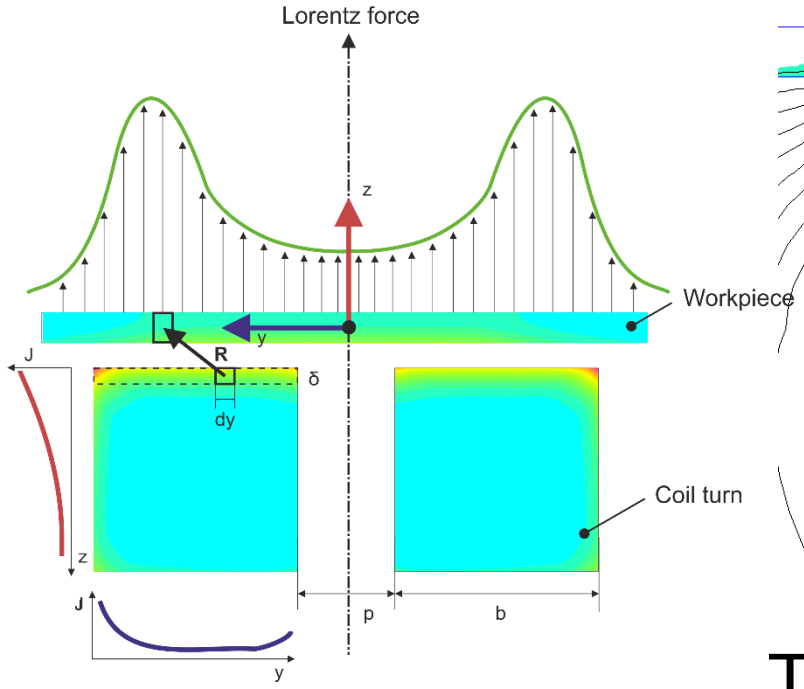
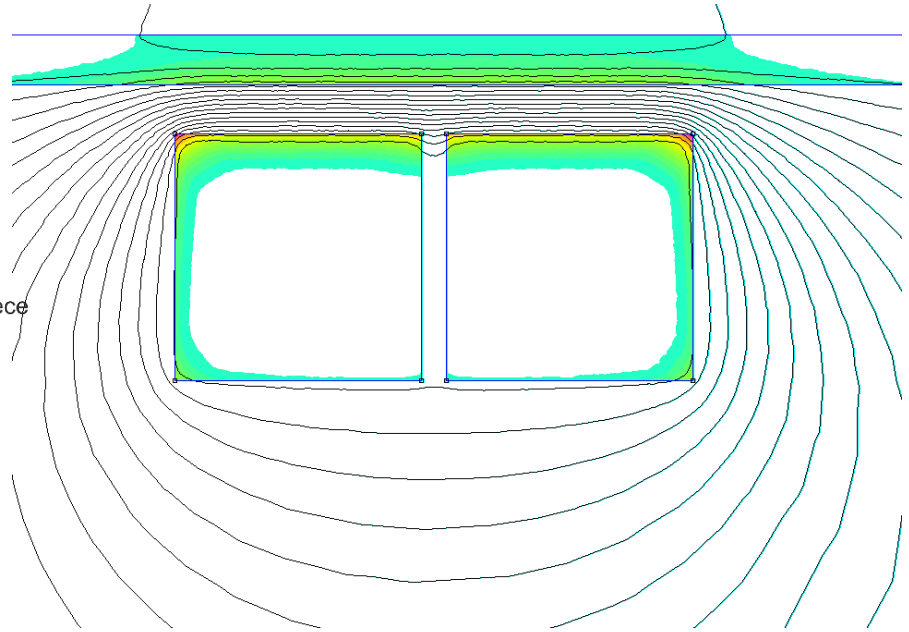
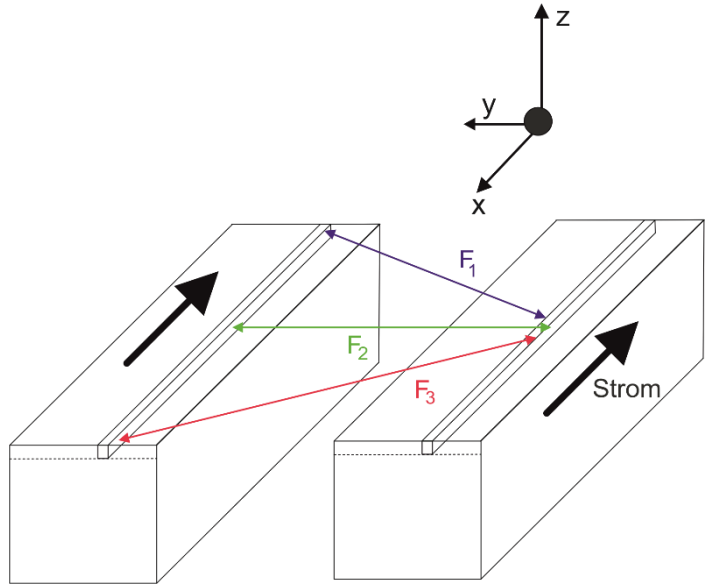
Conclusion and outlook

- Development of a semi-analytical model, without additional time needed to solve multiple coil turns
- Use of numerical current density distribution unavoidable
- LS-Dyna modeling replaceable for some cases







Thank you for your attention

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