12th OpenModelica Annual Workshop
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a full text version of this
presentation is available at:
arXiv:2001.09638v1 [eess.SY]
https://arxiv.org/abs/2001.09638

Influence of Iron Losses on Switching Dynamics of an Electromagnet from Experiment and Simulation

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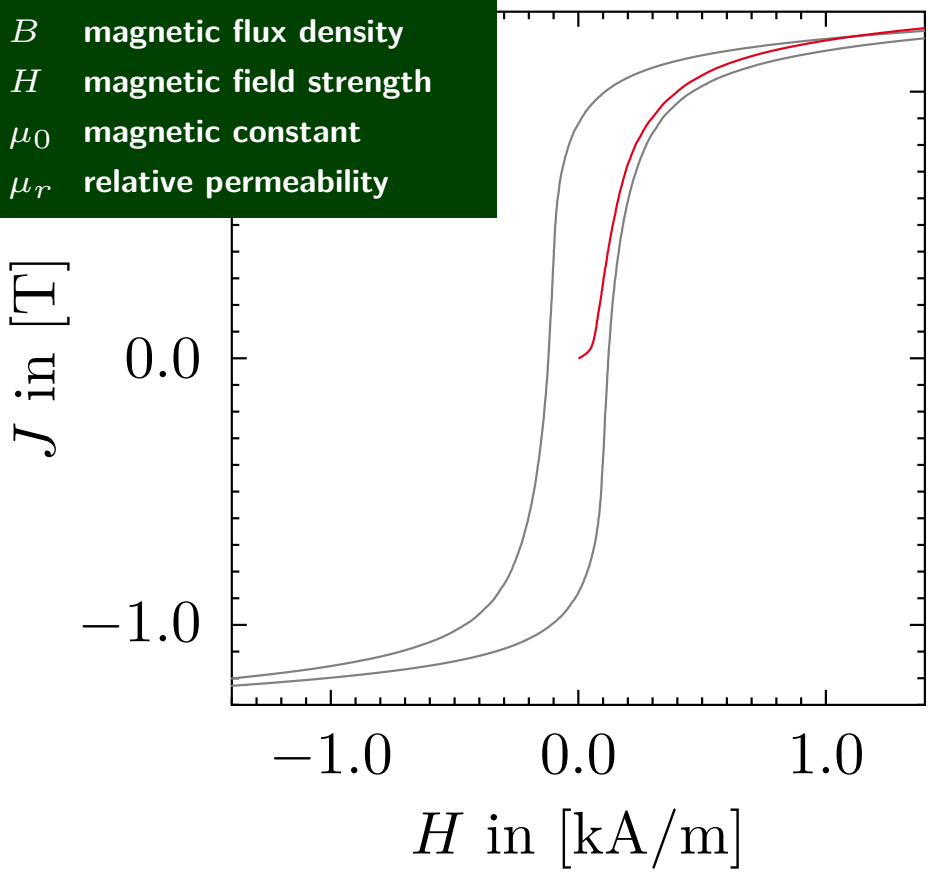
Soft Magnetic Material

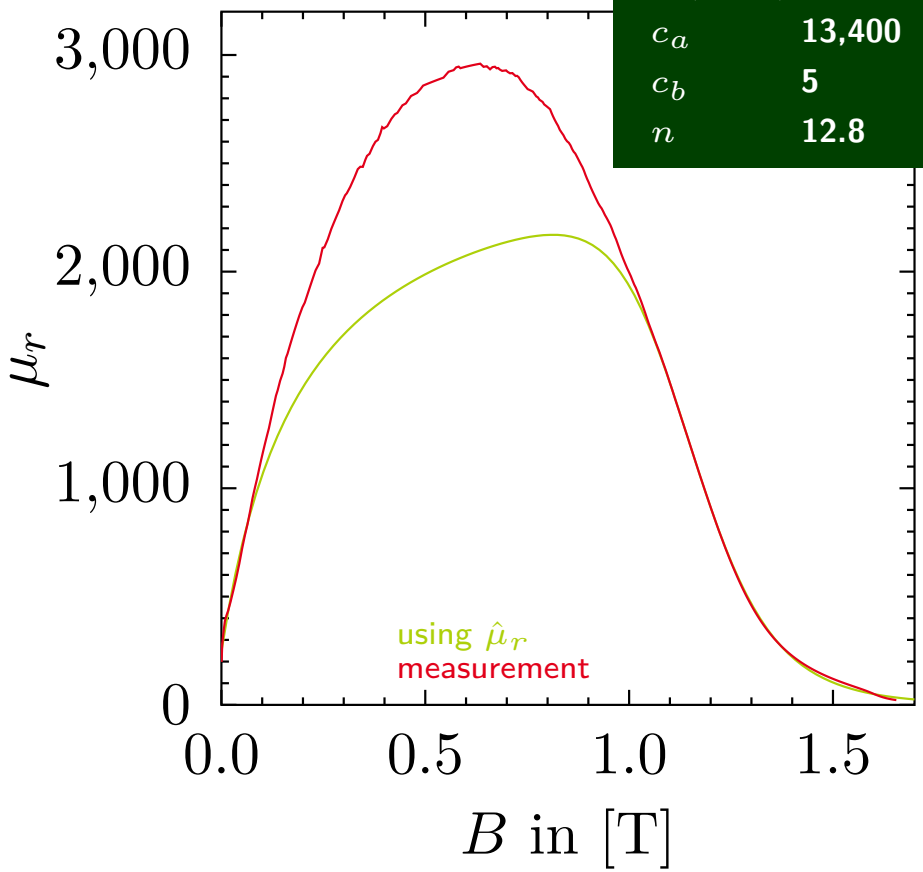
$B = \mu_0 \mu_r H = J + \mu_0 H$

J	magnetic polarization
B	magnetic flux density
H	magnetic field strength
μ_0	magnetic constant
μ_r	relative permeability

X6CrMoS17 (1.4105)
ASTM A838, Alloy Type 2



μ_i	246
$B(\mu_{\max})$	0.995 T
c_a	13,400
c_b	5
n	12.8



$$\hat{\mu}_r(B) = 1 + \frac{\mu_i - 1 + c_a B_N}{1 + c_b B_N + B_N^n} \quad \text{where:} \quad B_N = \left| \frac{B}{B(\mu_{\max})} \right|$$

Soft Magnetic Material: Tellinen Model

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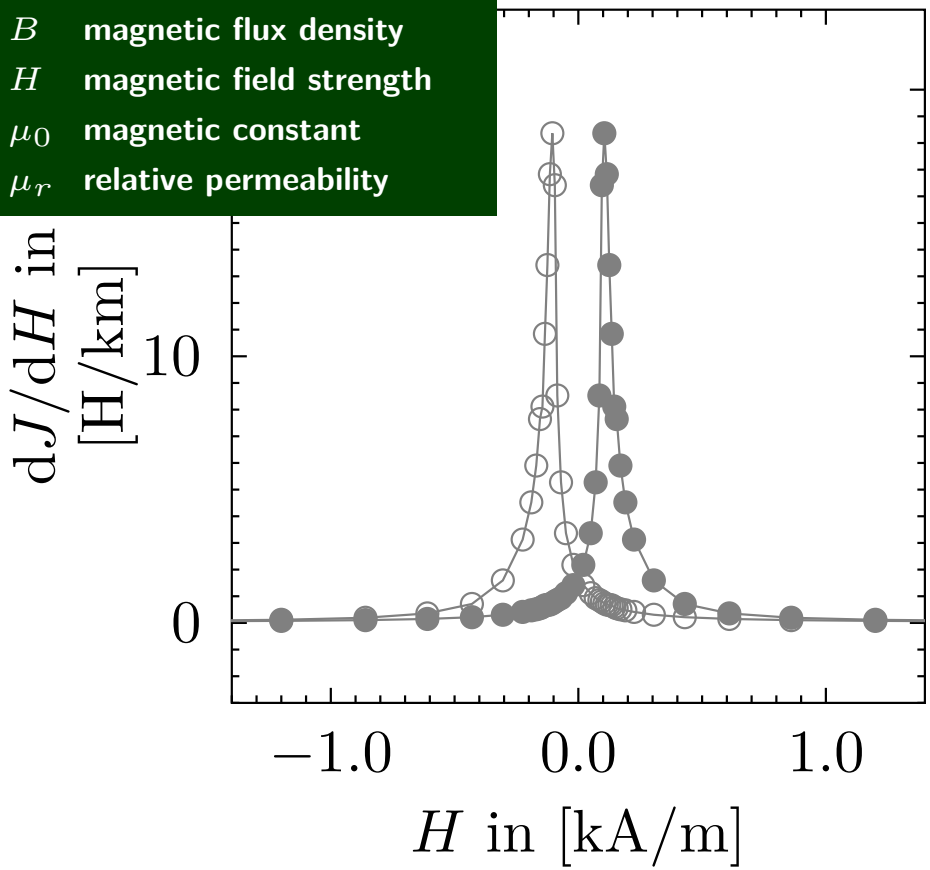

$$\frac{\mathrm{d}J}{\mathrm{d}H} = \begin{cases} \frac{J_- - J}{J_- - J_+} \frac{\mathrm{d}J_+}{\mathrm{d}H} & \text{if } \mathrm{d}H > 0 \\ \frac{J - J_+}{J_- - J_+} \frac{\mathrm{d}J_-}{\mathrm{d}H} & \text{if } \mathrm{d}H < 0 \\ 0 & \text{else} \end{cases}$$

Tellinen: *A Simple Scalar Model of Magnetic Hysteresis*, IEEE Transactions on Magnetics **34**, 2200 (1998)

Soft Magnetic Material: Tellinen Model

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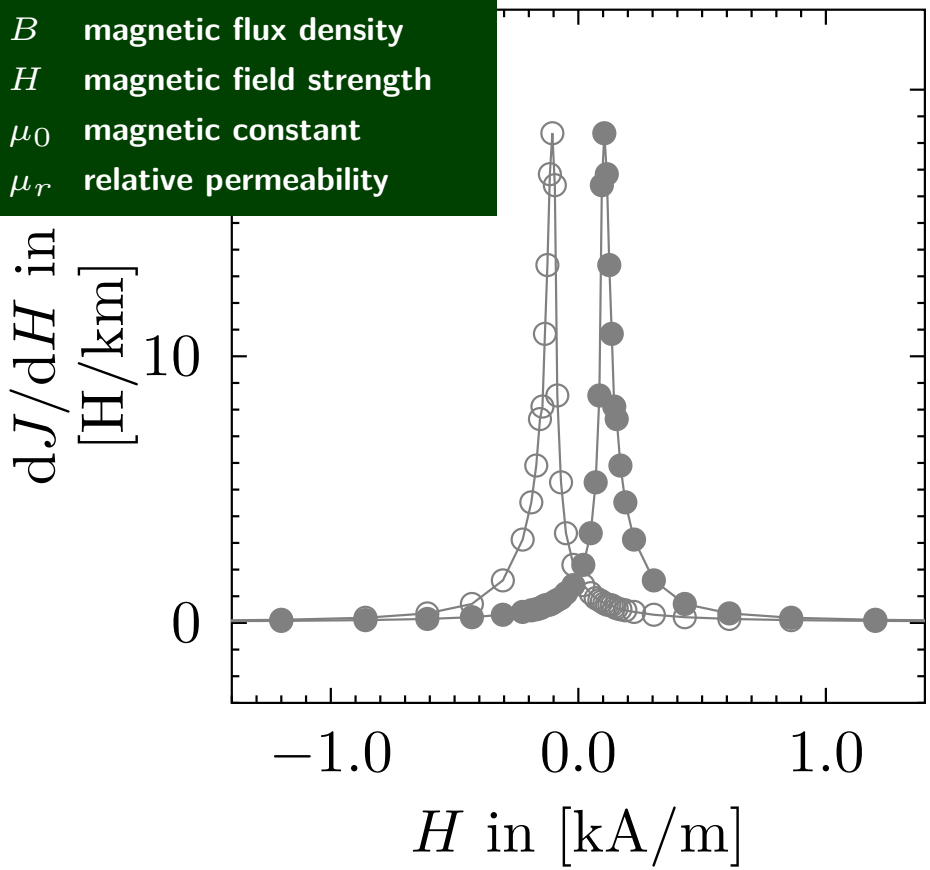
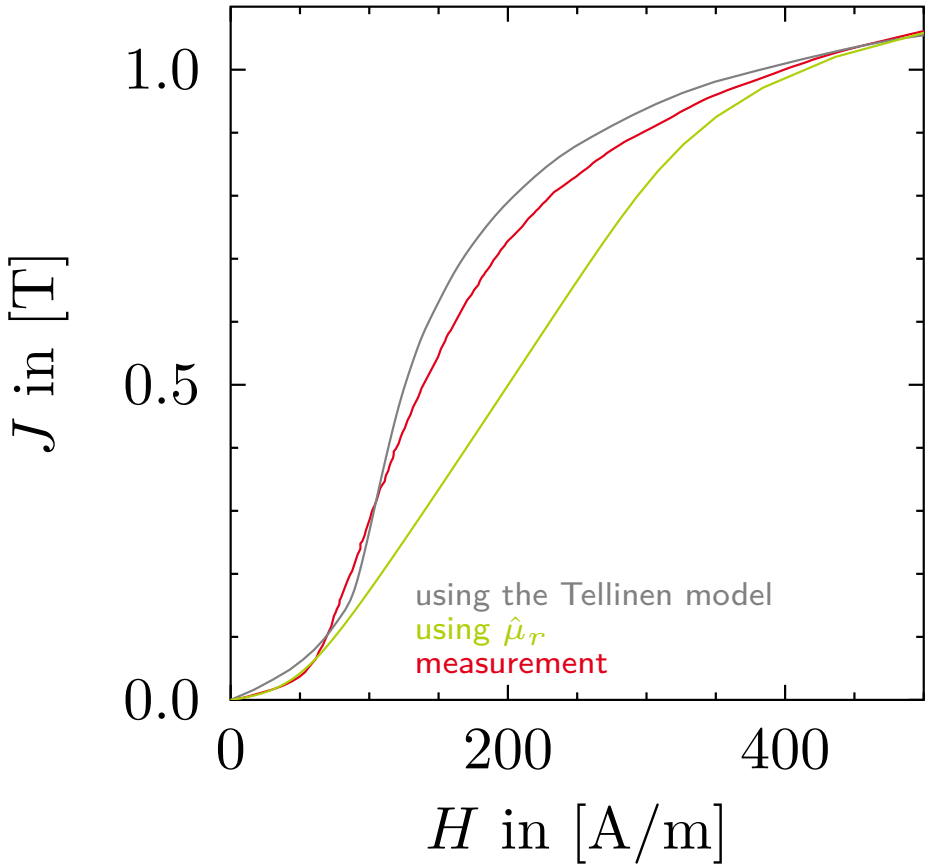
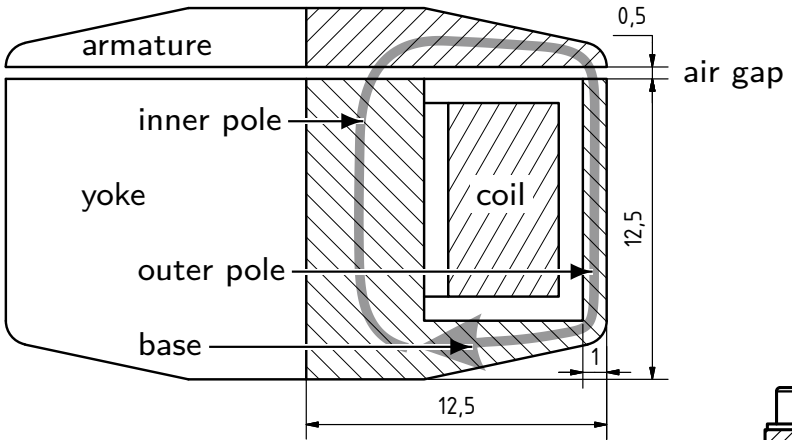
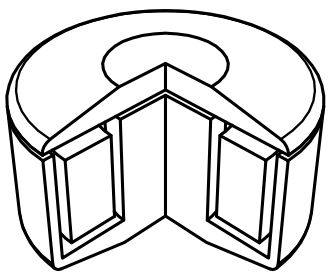
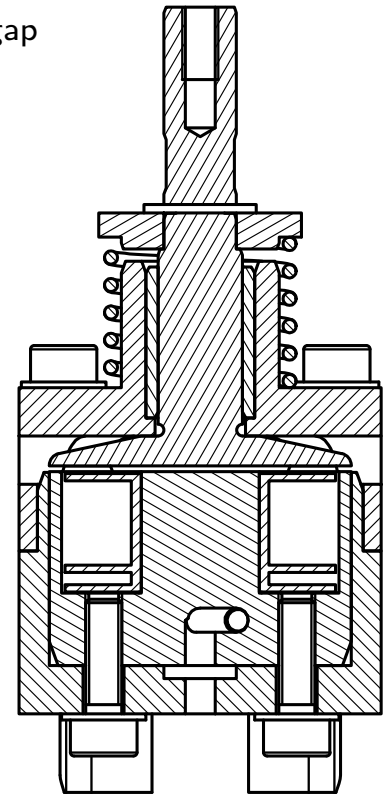




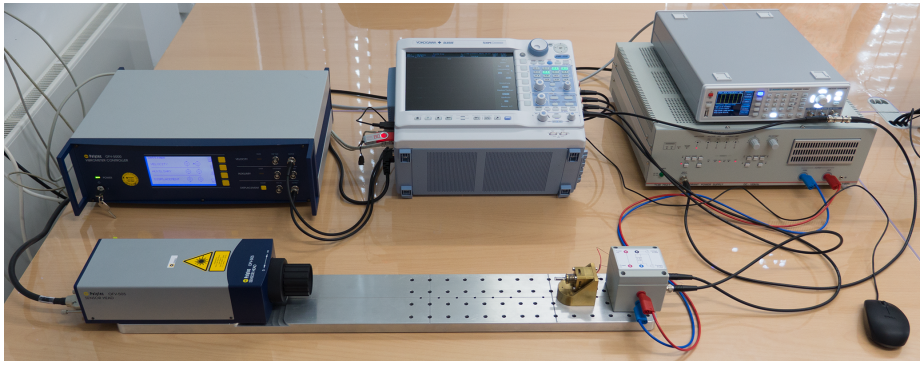


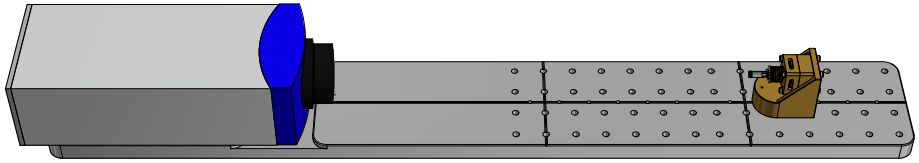




Schmidt and Hacia: *Magnetic Force from Experiment, Equation- and Geometry-based Calculation using the Example of a Switching Magnet*, Proc. EOOLT19, Berlin, Germany (2019) pp. 67–76

Laser Test Rig for Dynamical Testing





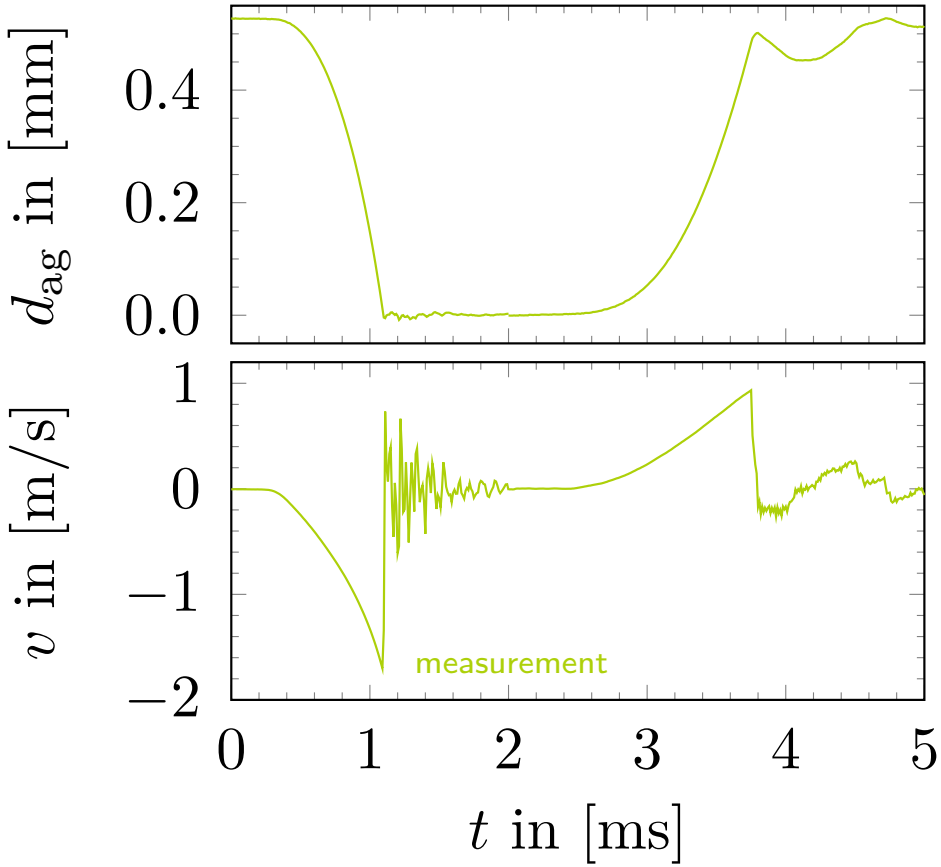
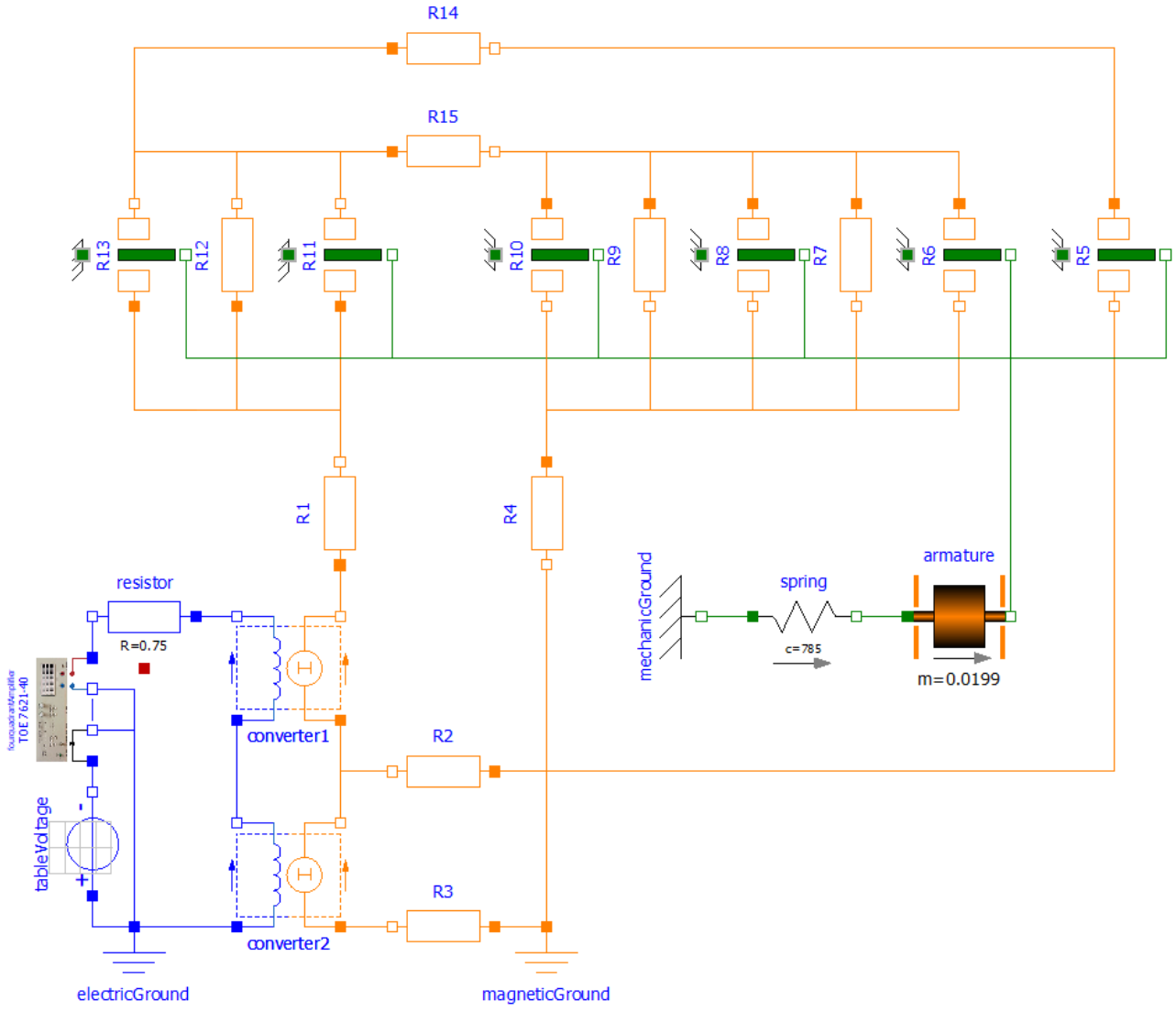
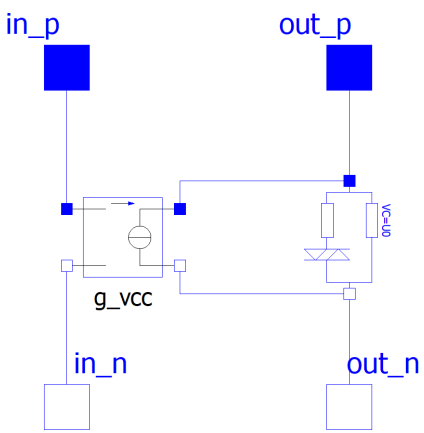


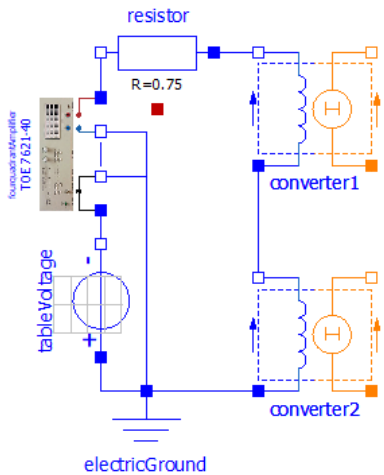
Diagram View – Quasistatic to Dynamic

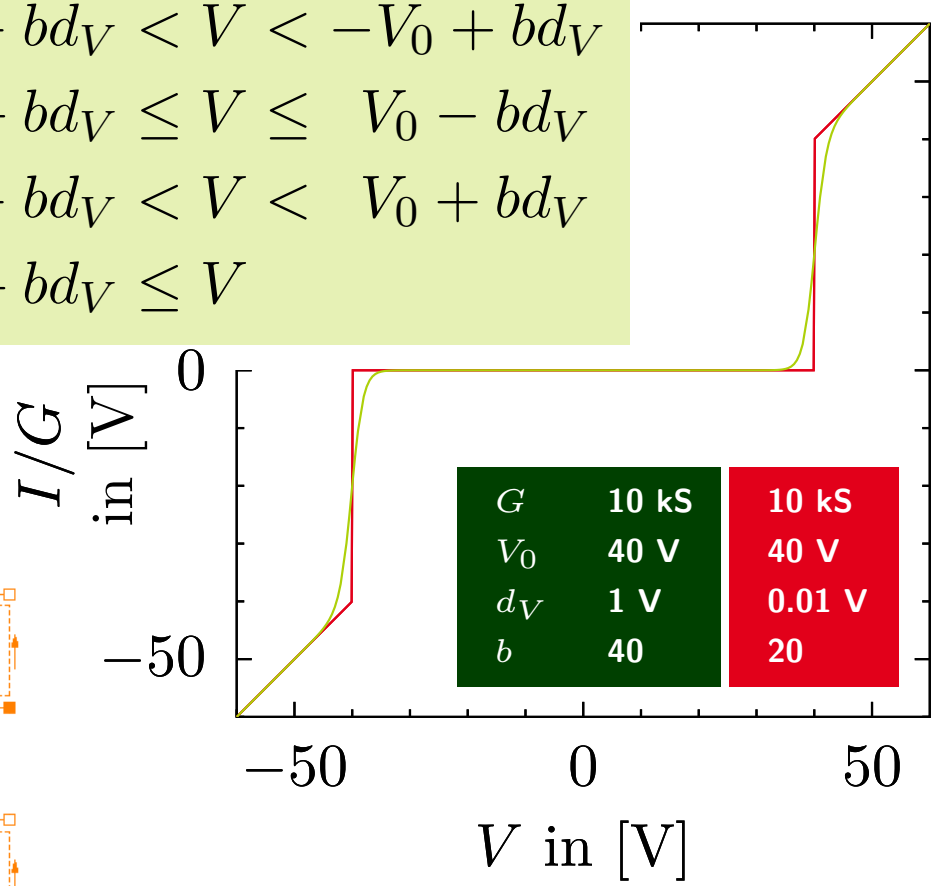


Modeling the Four-Quadrant-Amplifier

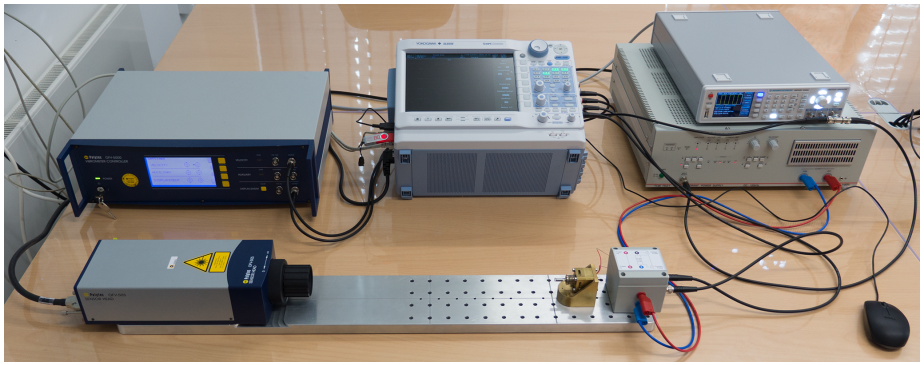
$$\frac{I}{G} = \begin{cases} \frac{V}{1+\exp(-b)} & \text{if: } V \leq -V_0 - bd_V \\ \frac{V}{1+\exp((V_0+V)/d_V)} & \text{if: } -V_0 - bd_V < V < -V_0 + bd_V \\ \frac{V}{1+\exp(+b)} & \text{if: } -V_0 + bd_V \leq V \leq V_0 - bd_V \\ \frac{V}{1+\exp((V_0-V)/d_V)} & \text{if: } V_0 - bd_V < V < V_0 + bd_V \\ \frac{V}{1+\exp(-b)} & \text{if: } V_0 + bd_V \leq V \end{cases}$$







Checking Simulation against Experiment



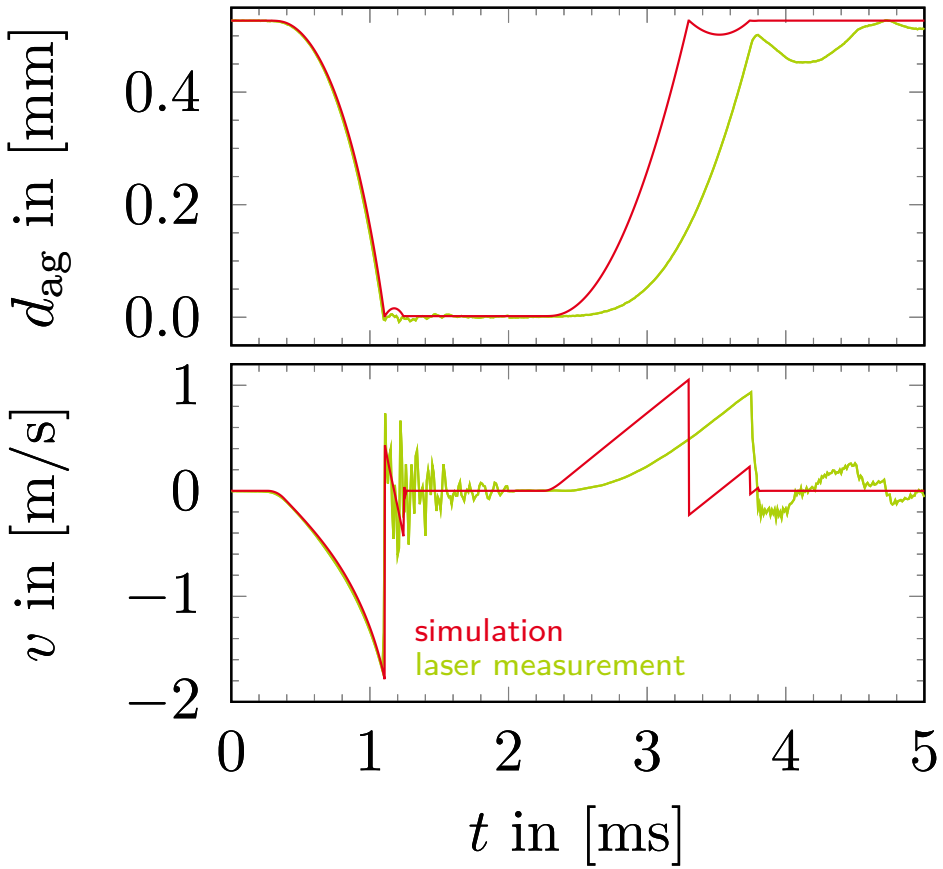
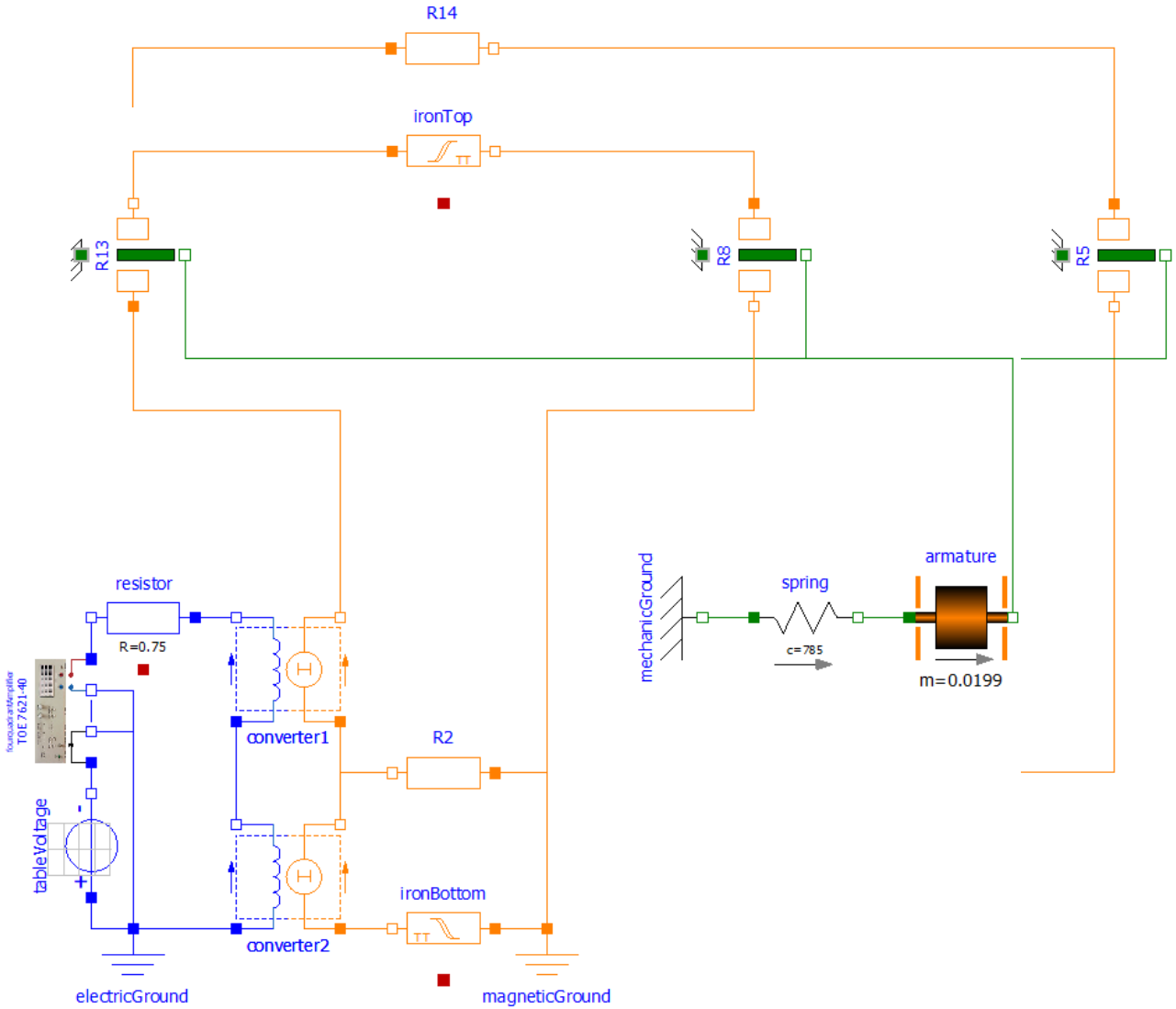


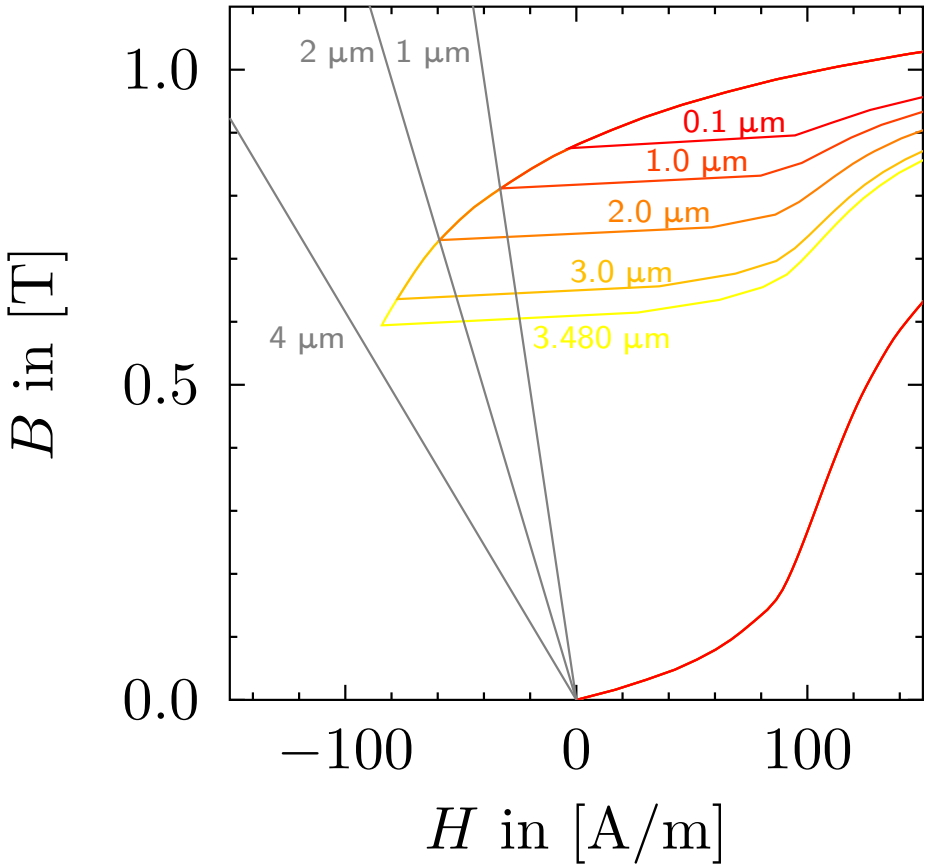
Diagram View – Hysteresis Losses



Ziske and Böderich: *Magnetic Hysteresis Models for Modelica*, Proceedings of the 9th International Modelica Conference, Munich, Germany (2012)

Influence of Hysteresis - Residual Airgap

magnet does not open



magnet opens

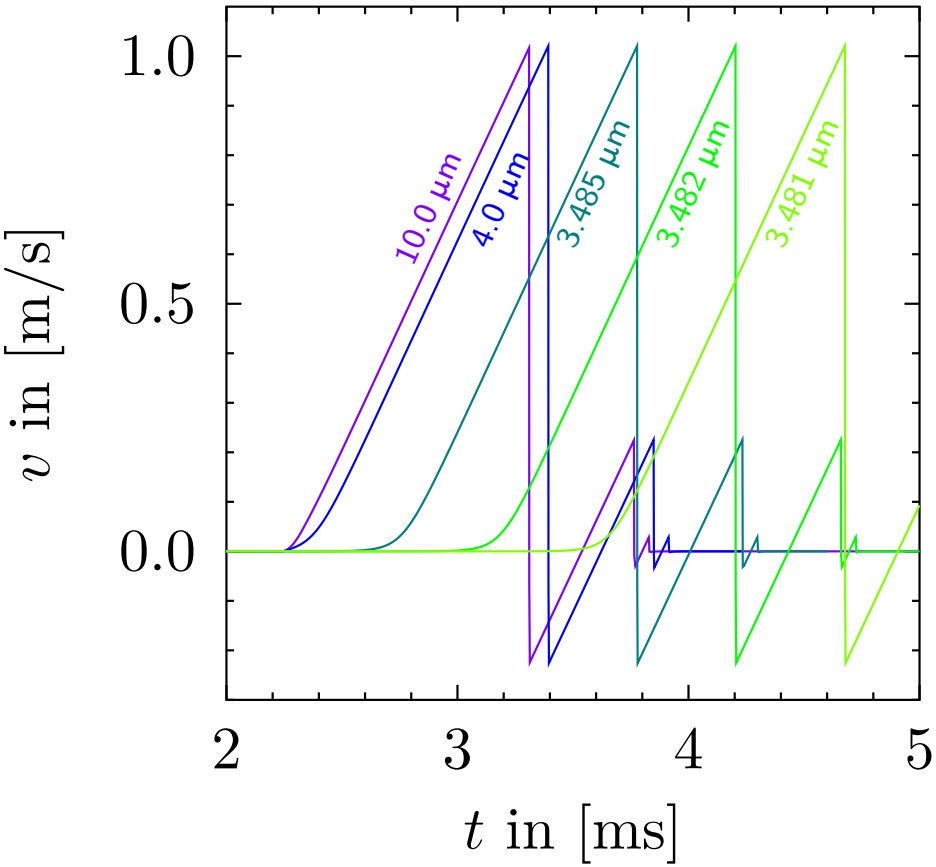
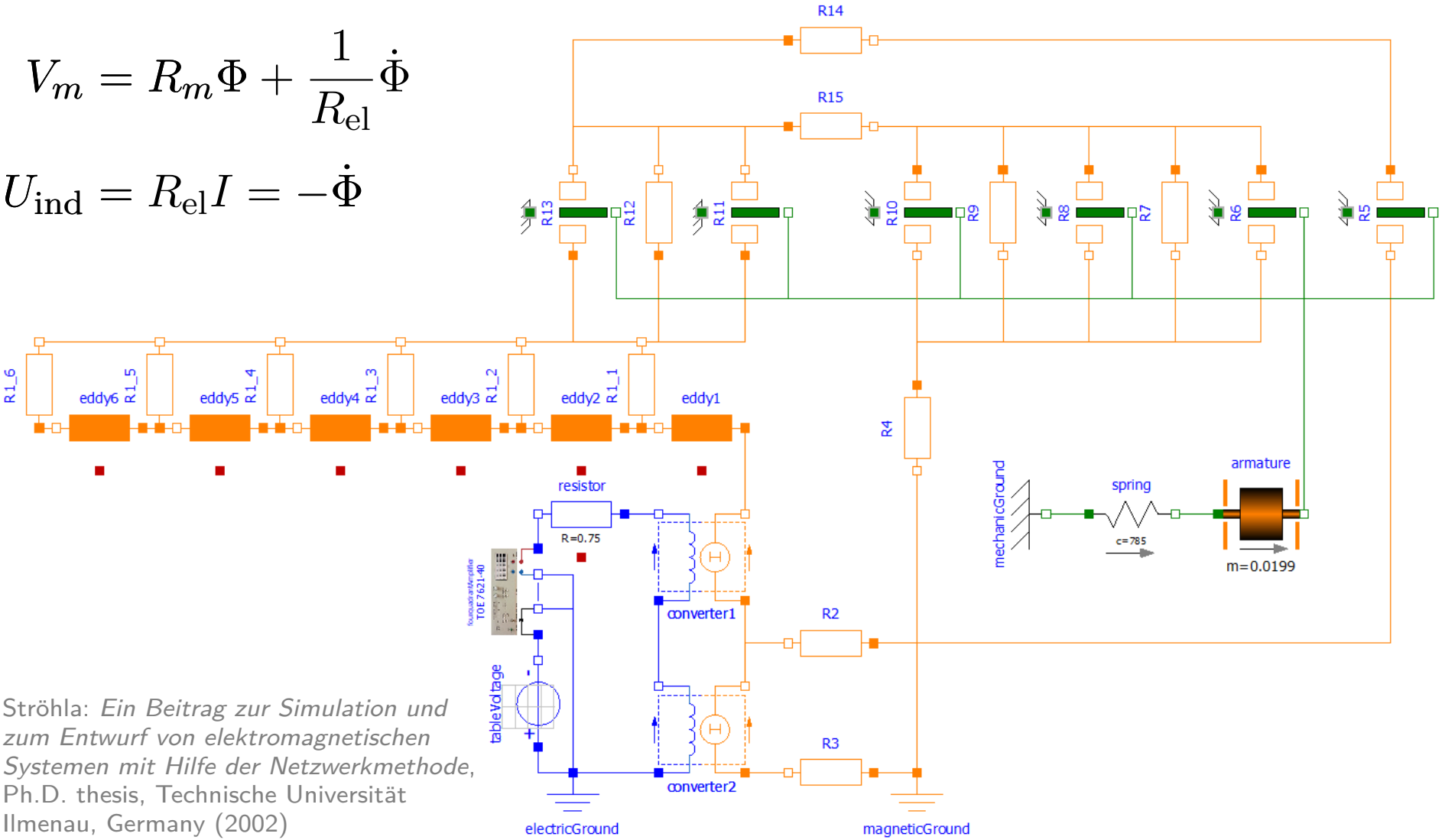


Diagram View – Eddy Current Losses

$$V_m = R_m \Phi + \frac{1}{R_{\mathrm{el}}} \dot{\Phi}$$

$$U_{\mathrm{ind}} = R_{\mathrm{el}} I = -\dot{\Phi}$$



Ströhla: *Ein Beitrag zur Simulation und zum Entwurf von elektromagnetischen Systemen mit Hilfe der Netzwerkmethode*, Ph.D. thesis, Technische Universität Ilmenau, Germany (2002)

Influence of Eddy Currents