NUMERICAL ANALYSIS OF THE RESPONSE OF THICK WIRES TO EXTREME DYNAMIC ELECTRO-MECHANICAL LOADS

COMSOL CONFERENCE 2014

September 17 - 19, 2014, Churchill College, Cambridge

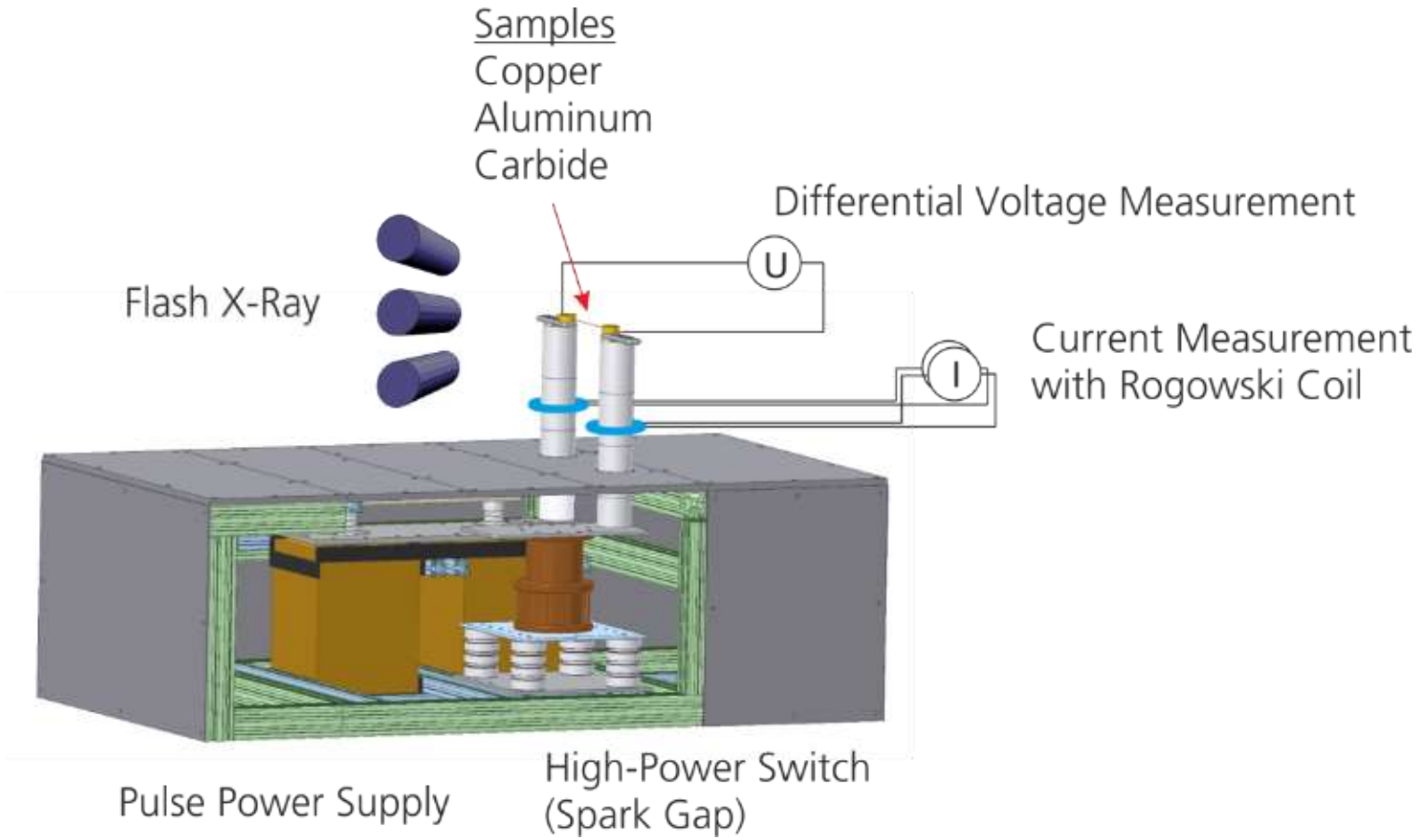
Fraunhofer EMI

Objective

- The objective of this work is to develop an understanding to describe the mechanical response of structural components in response to a short-term and dynamic electrical load.
- Such electrical loads can be observed in nature with flashes that have currents of tens to hundreds of kilo amperes.

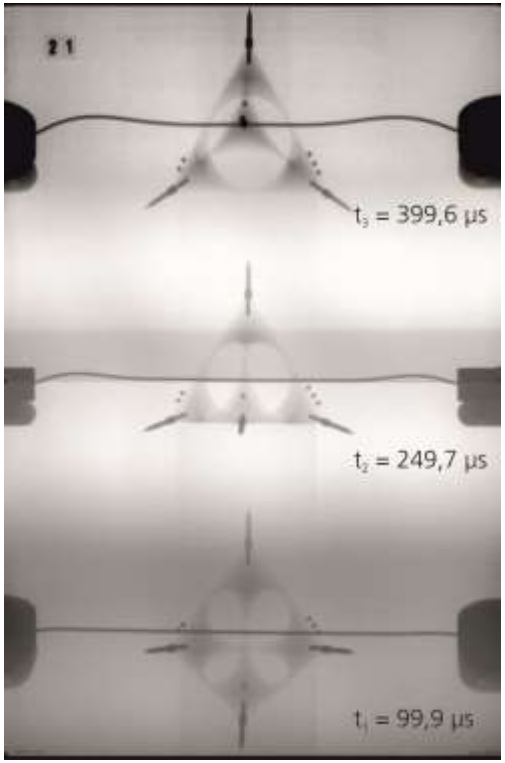
[1] http://www.srh.noaa.gov/jetstream/lightning/positive.htm
[2] Berger, K., 1977: The earth ash. In: Lightning, Vol. 1: Physics of Lightning. | R.H. Golde, ed., Academic Press, San Diego, S. 119{190.

Schematic drawing of the experimental set-up for investigation of wire explosion processes



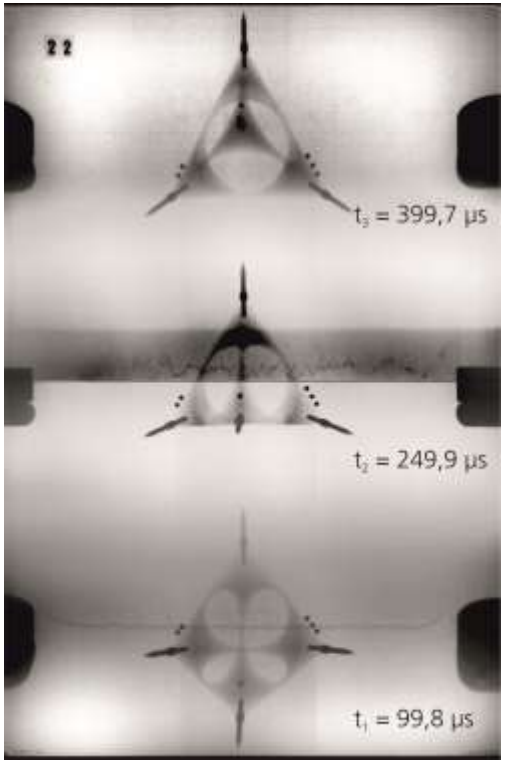
Experimental results

Copper



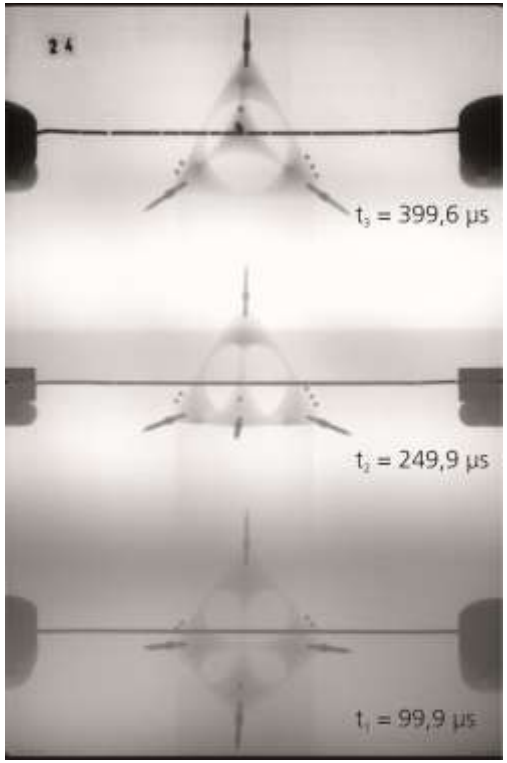
Thermal Expansion

Aluminum



Wire Explosion

Tungsten Carbide



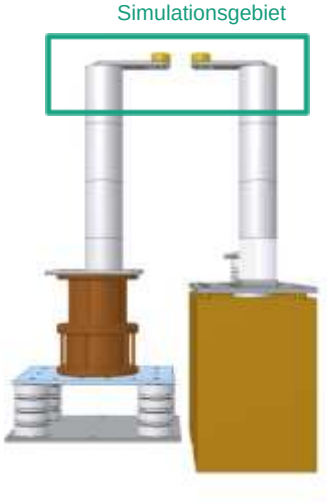
Wire Fragmentation

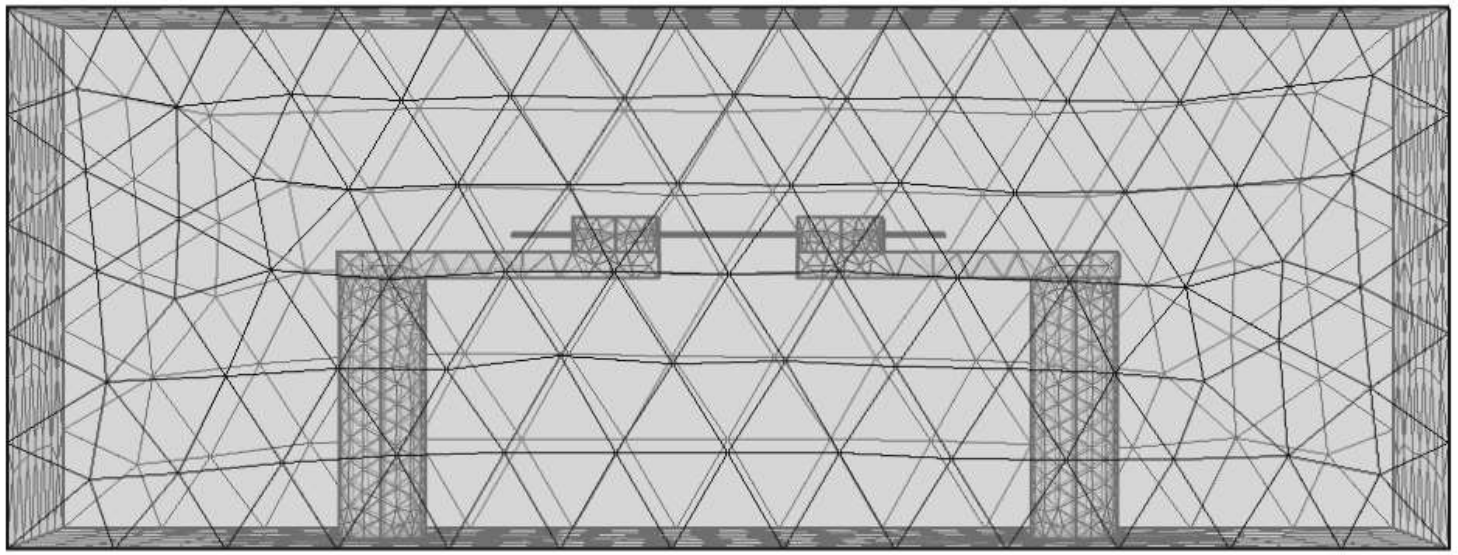
The initial energy of the system contains about 6,5 kJ

Cunrath, Richard; Kuder, Jürgen; Nau, Siegfried Dr.; Wickert, Matthias Dr.: Interaction of extreme electric currents with metals. In: 27th International Symposium on Ballistics, S. 1877–1884.

Model

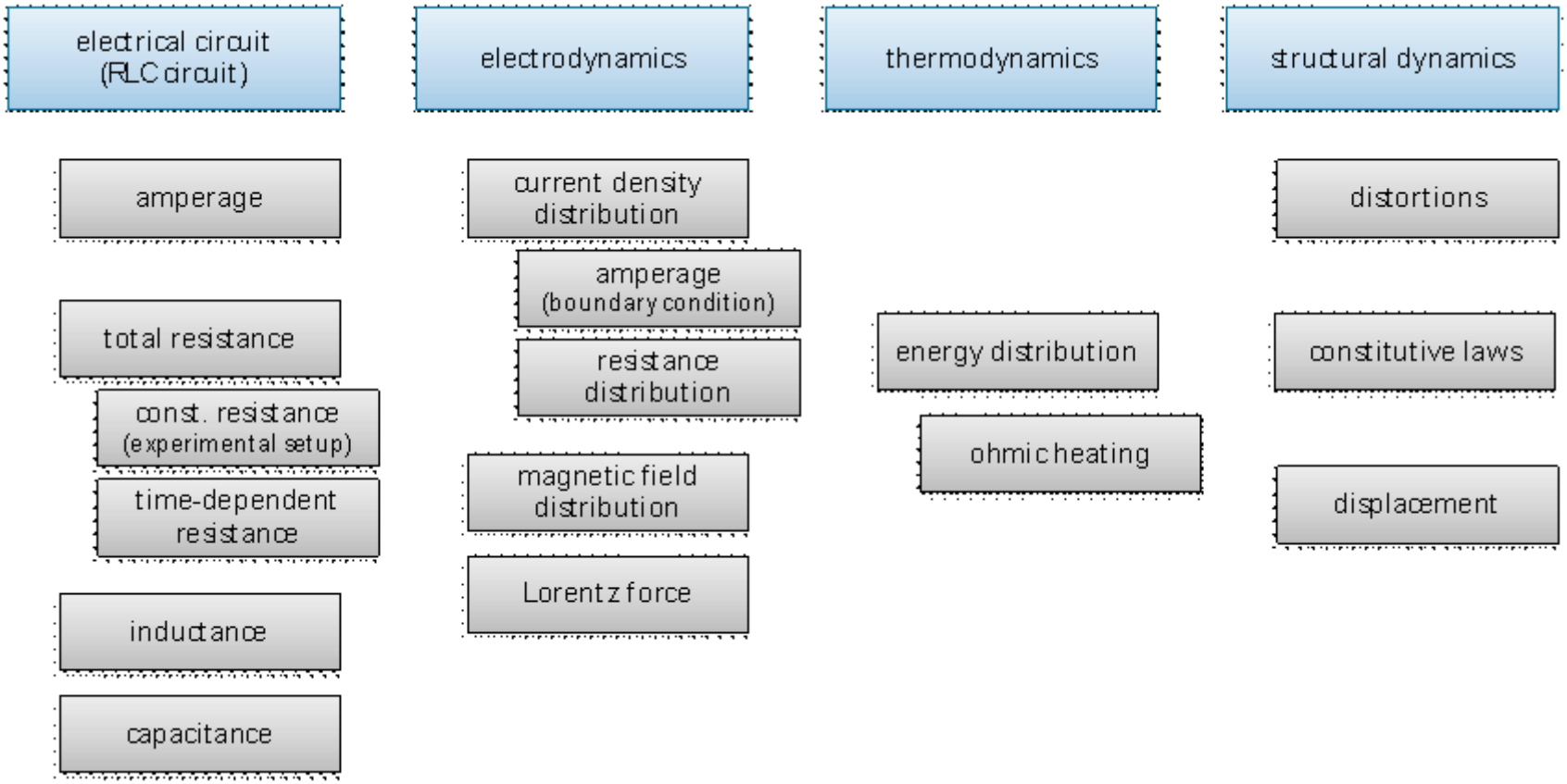
Geometry adopted in COMSOL Multiphysics





Model

Coupling of the physical effects



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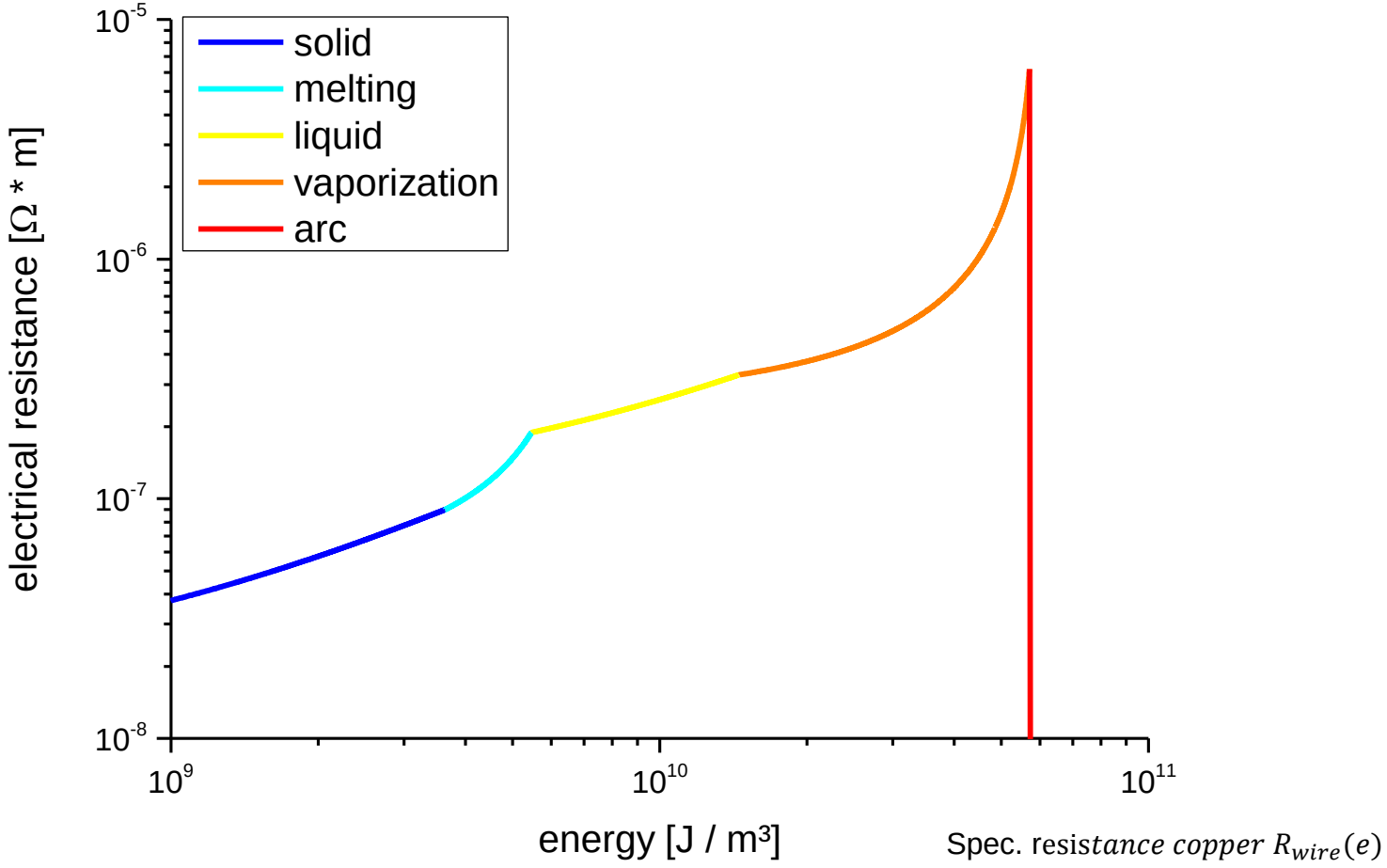
Modellierung

Temperature-dependent resistance

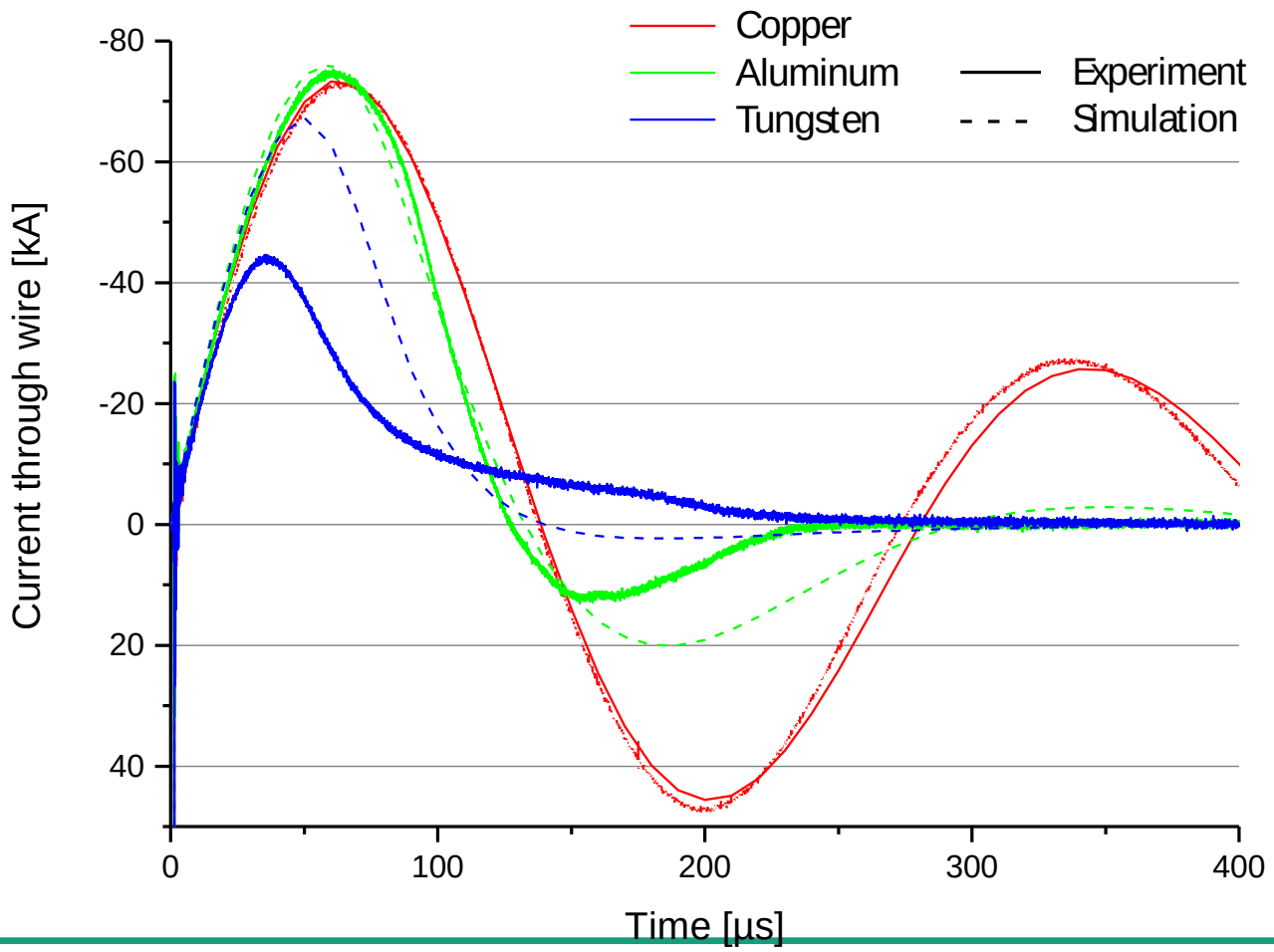


Tucker, T.J. and R.P. Toth, A computer code for the prediction of the behaviour of electrical circuits containing exploding wire elements

S. Ebenhöch 2011, Charakterisierung von EFI-Zündsystemen auf der Basis physikalischer und schaltungstechnischer Modellierung, Fraunhofer EMI, E39/10

Numerical results

Current



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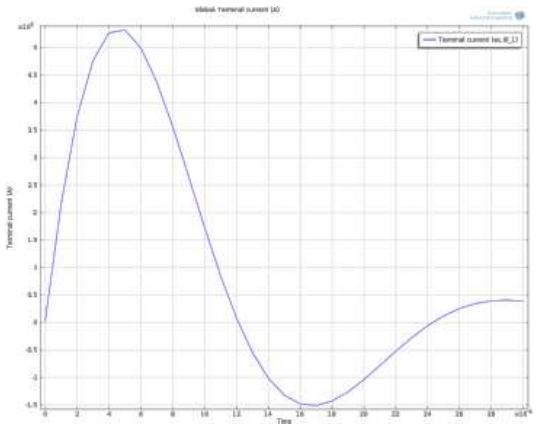
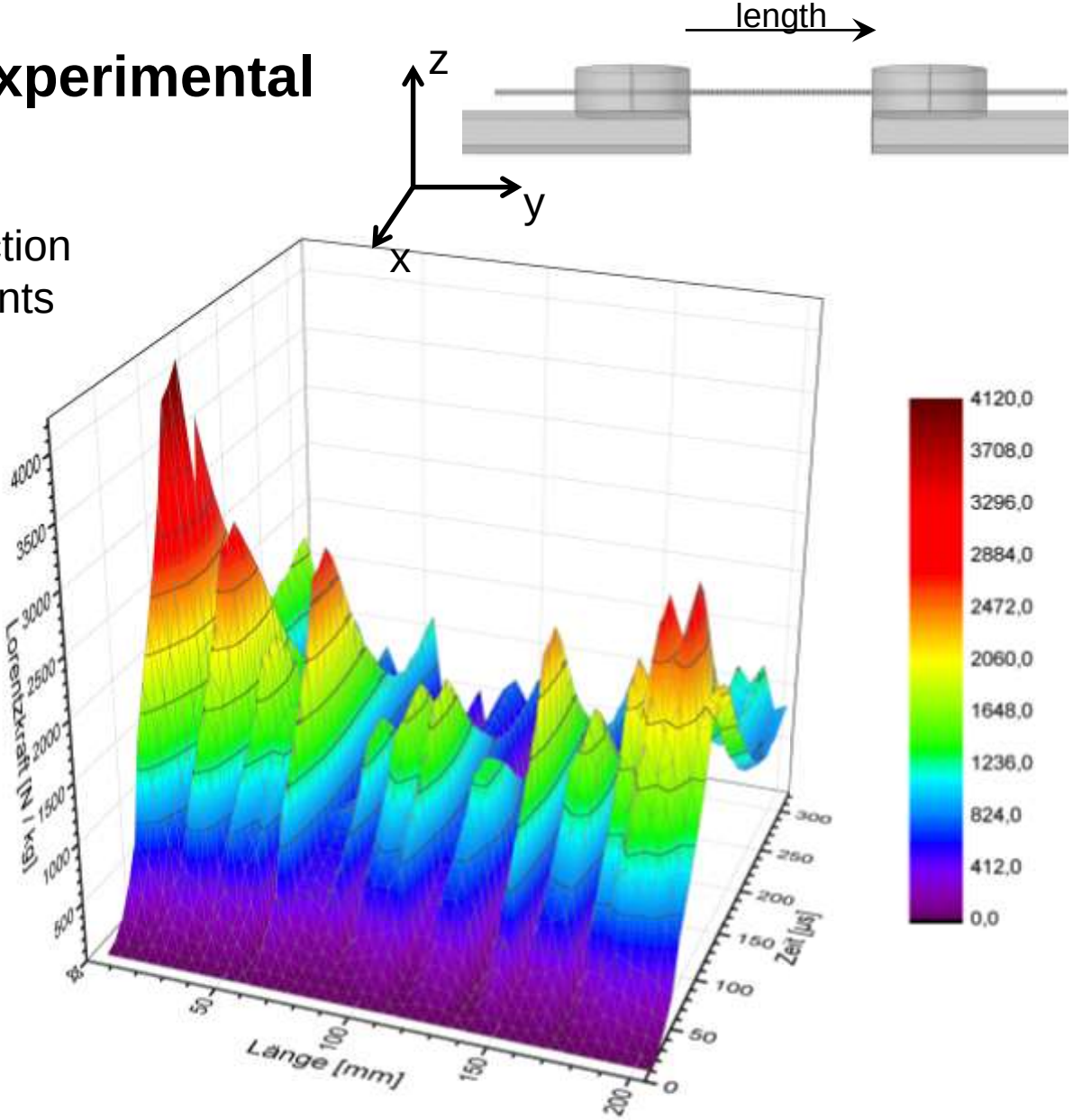
Influences of the experimental setup

Lorentz force in the z-direction onto 2mm long wire elements

$$F_z = j_x \cdot B_y - j_y \cdot B_x$$

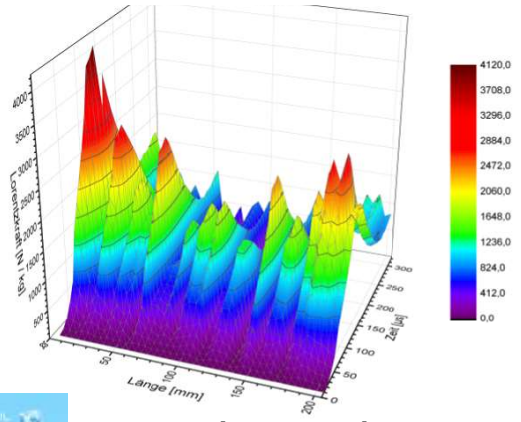




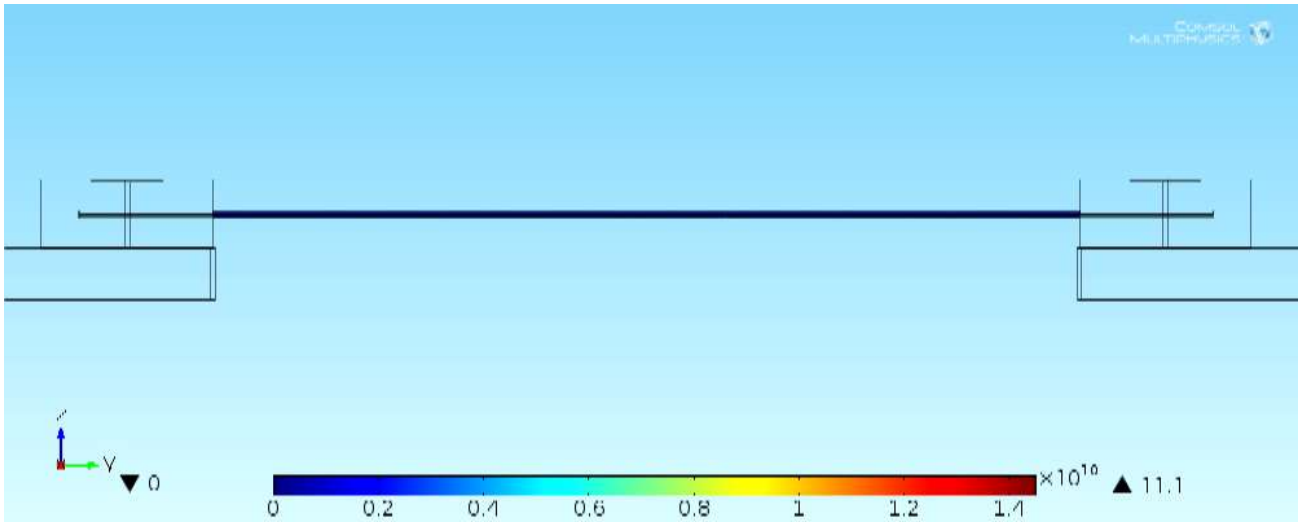
Fraunhofer EMI

Numerical results

State of the copper wire



Deflection of the copper wire due to the Lorentz force acting on it



Excessive representation of displacement by a factor of 10

Color scale:
Internal energy e

melt phase

$$e = 0{,}55 \cdot 10^{10} \frac{J}{m^3}$$

liquid phase

$$e = 1{,}45 \cdot 10^{10} \frac{J}{m^3}$$

Conclusion

With COMSOL Multiphysics, it is possible to calculate the coupled effects

Influences that influence the structural-mechanical calculation.

- Increase of internal energy by Joule heating is included in the equation of state p (V, E).
- Maxwell's stress tensor (Lorentz force) is included in the structure-mechanical stress tensor as an additional term.

Influences that influences the electromagnetic calculation.

- Displacements caused a new geometry (eg. Changing the inductance change of the magnetic field)
- Increasing the internal energy changes the electrical resistance