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Coupled FEM-Simulation of Magnetic Pulse Welding for Nonsymmetric Applications

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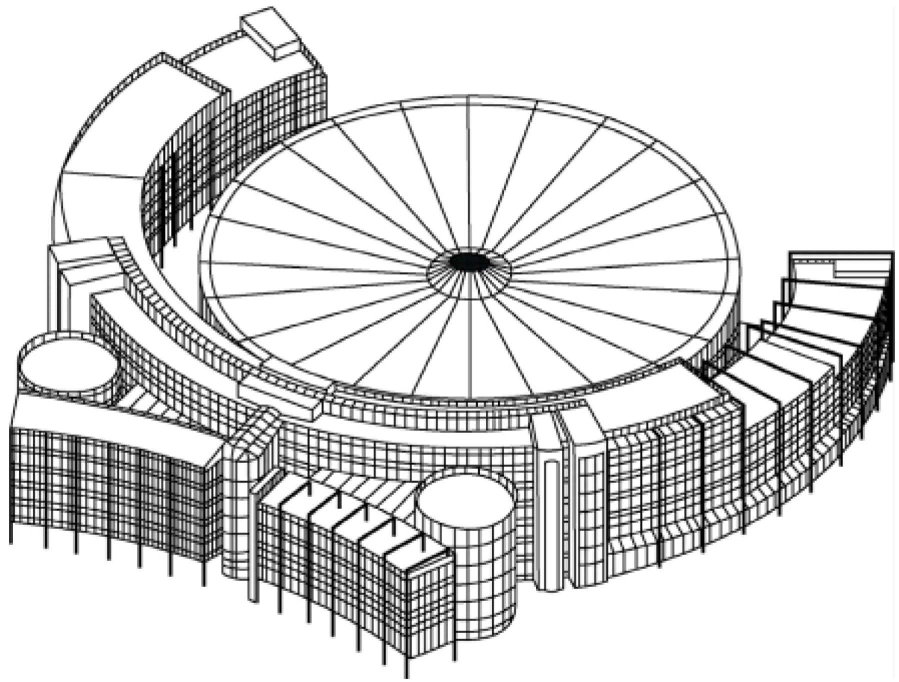

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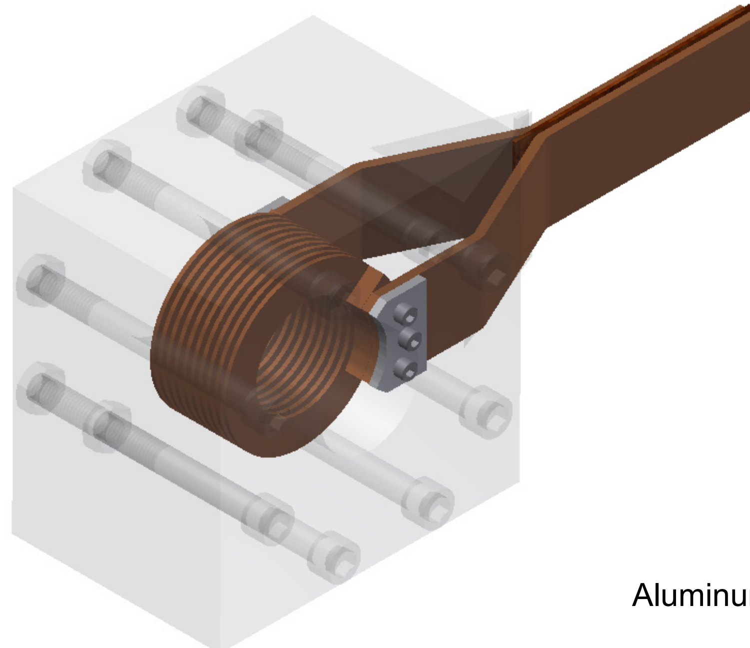
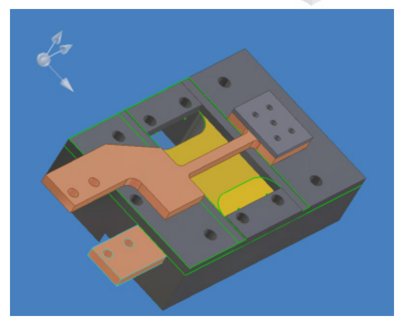
- Introduction
- Process details
- Model details
- Simulations
- Validation
- Conclusion

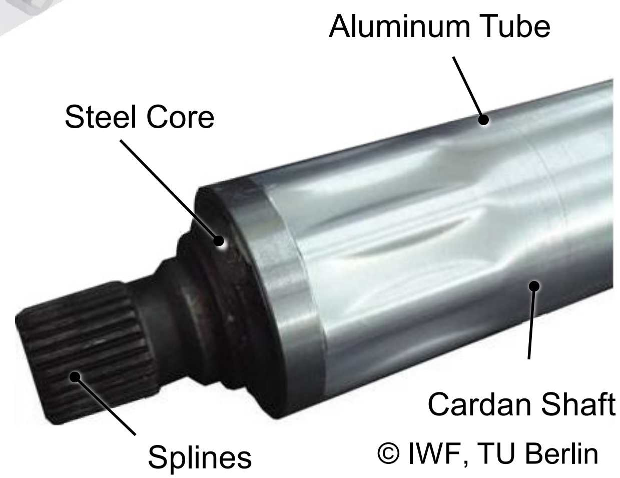
Introduction

Motivation

- High process forces
  - Necessitiy to manifest development and calculation procedures for tool coil design
- Complex physical process of binding
  - Necessity of model to indicate process parameters with guaranteed weldability
- Different specifications of impulse forming machine
  - Necessity of flexible model capable to reproduce the discharge behaviour







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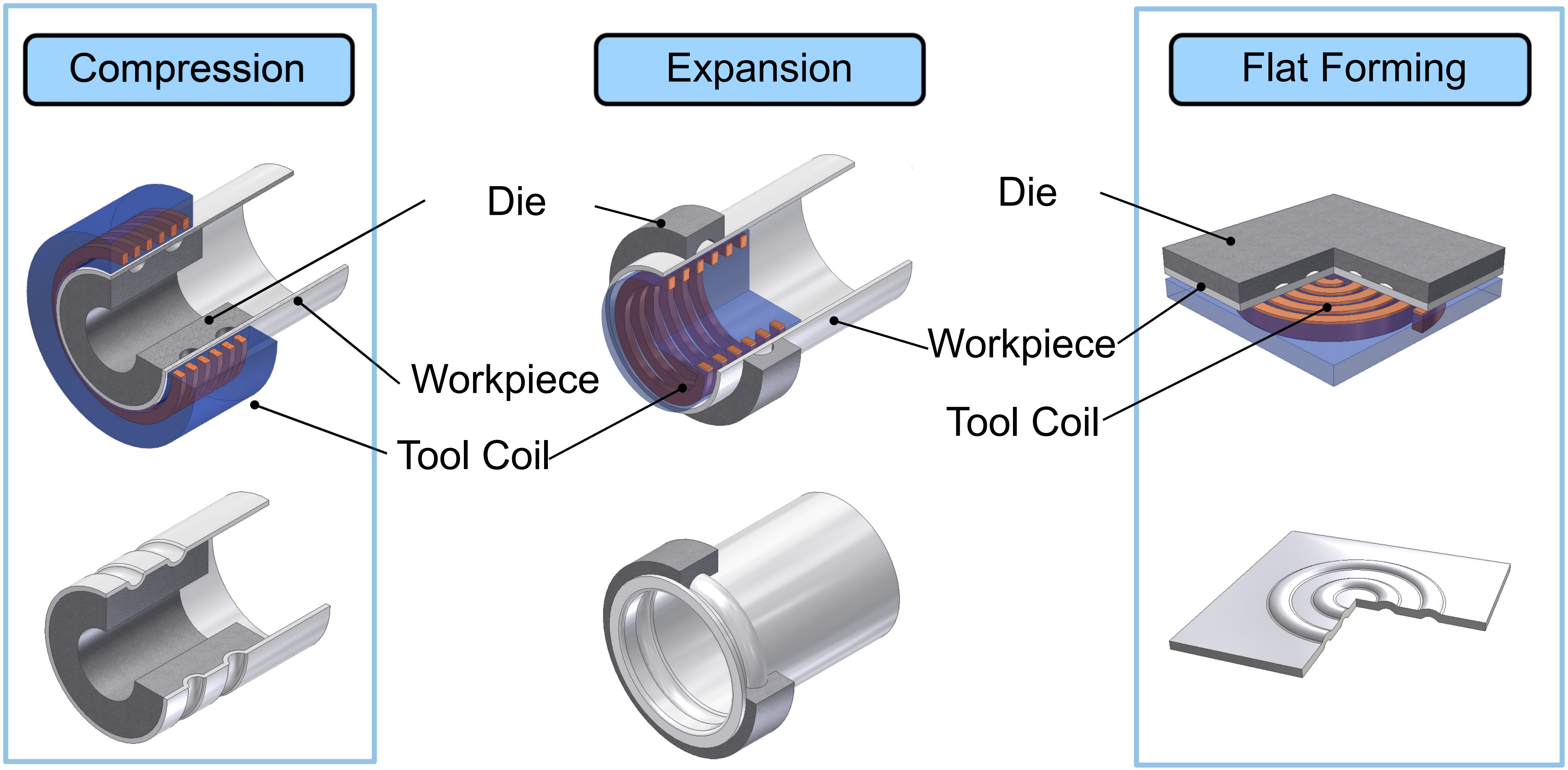
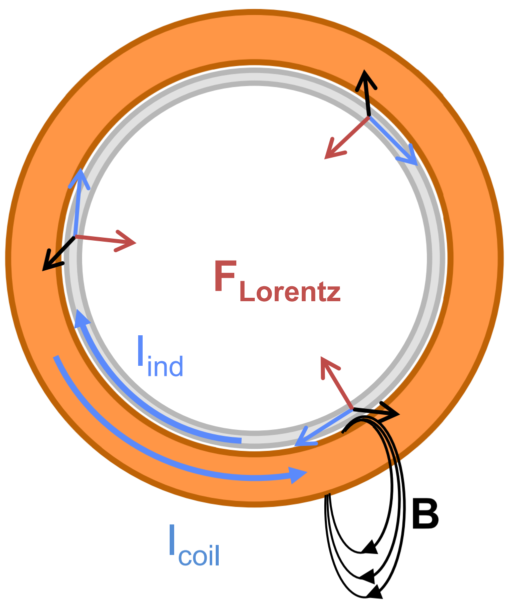
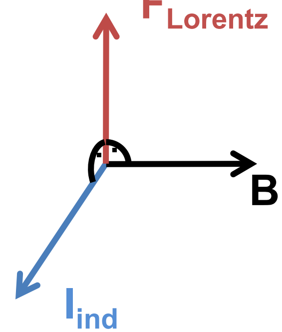
Introduction – Process Variants of Pulse magnetic Forming



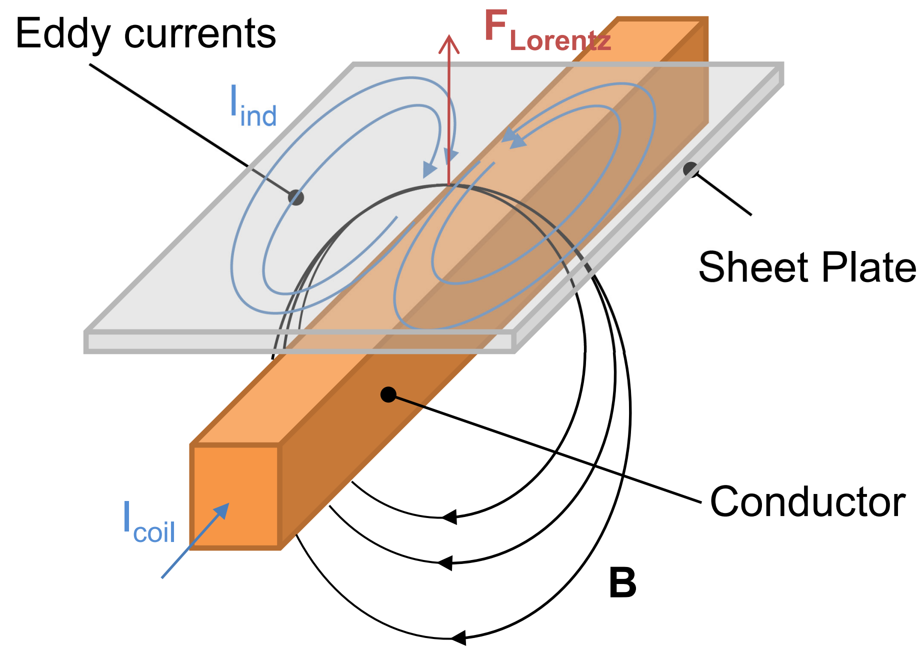
Process Details – Process Principle of Pulse magnetic Forming

Compression





Flat Forming



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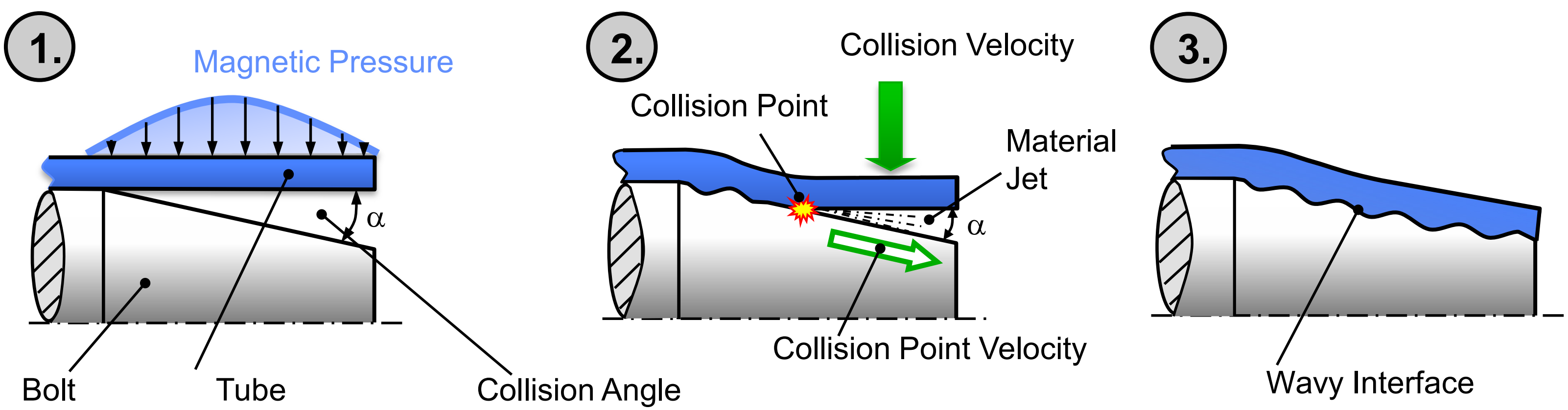
Process details – Process Principle of Pulse magnetic Welding

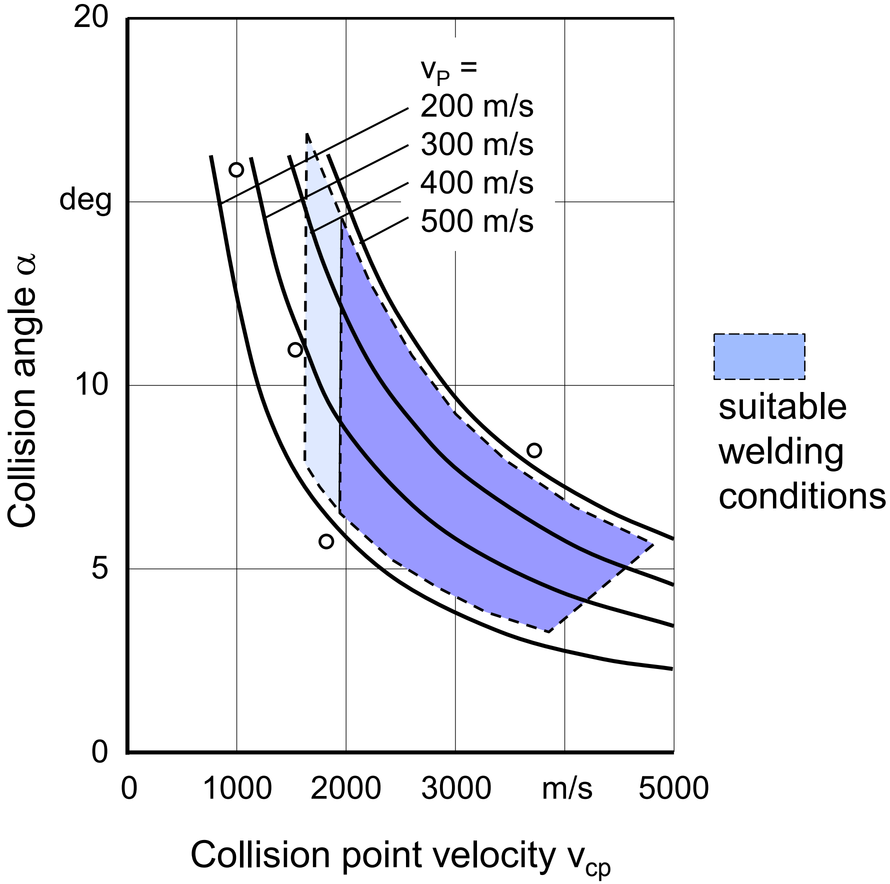
1.
- Due to magnetical pressure, the tube is accelerated to the center

2.
- At the collision point high pressures are developing
- A material jet is created at the collision point

3.
- Material within the contact zone changes to a highly viscous state
- This results in the formation of a wavy interface



Process details – Process Conditions of Pulse magnetic Welding



Process parameters at shock welding processes according to Kreye:

- Collision velocity v_P
- Collision point velocity v_{cp}
- Collision angle α

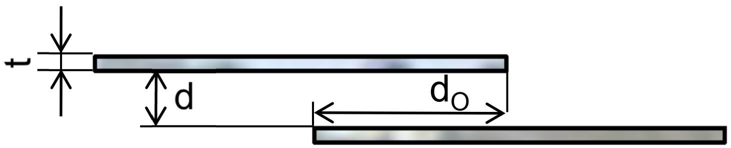
Further dependencies:

- Charging energy W_E
- Distance between probes d
- Overlap distance of probes d_O

Kreye, „Schweißen und Schneiden“, 1985, Vol. 37, pp 297-302

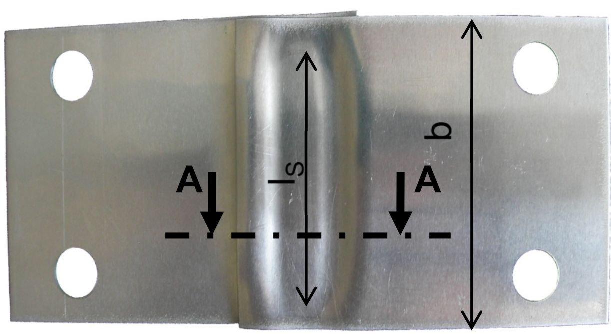
Process Details – relevant Parameters at Pulse magnetic Welding of Sheet Metals

Before welding

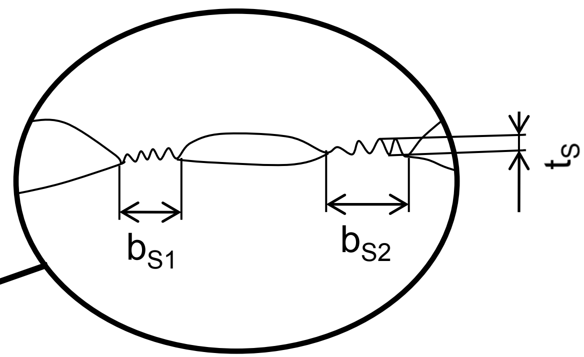


b: Breadth of metal sheet
t: Thickness of metal sheet
d: Distance of not yet welded metal sheets
d_O: Overlapping of not yet welded metal sheets

After welding

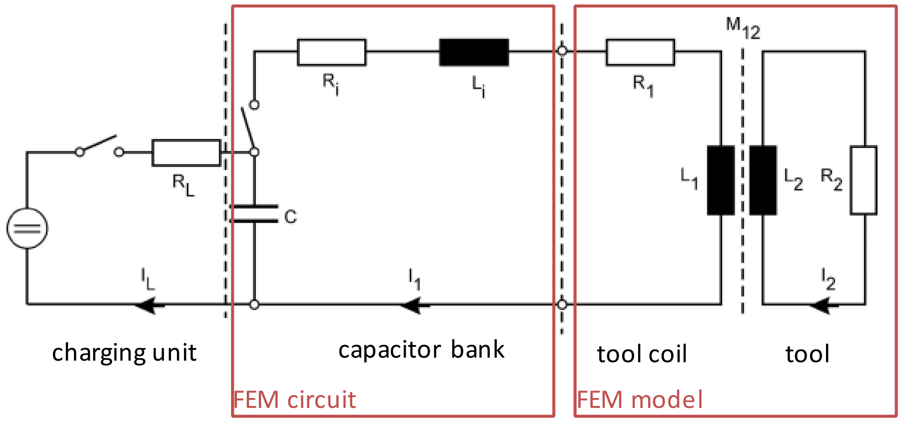


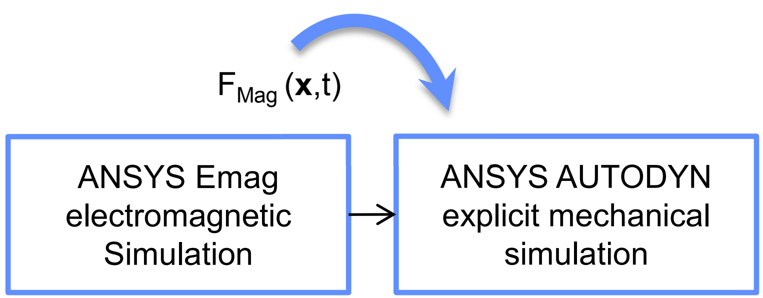
l_S: Length of weld seam
b_{Sx}: Breadth of weld seam S1/S2
t_S: Depth of weld seam



A - A

Model Details – Coupling Concept





- Capacitor Banks, cables and collector were modeled as a simple RCL-circuit
- Tool coil and workpiece were represented as FEM model
- Electromagnetic Simulation was carried out first in order to calculate the process forces
- Process forces were imposed on the mechanical model

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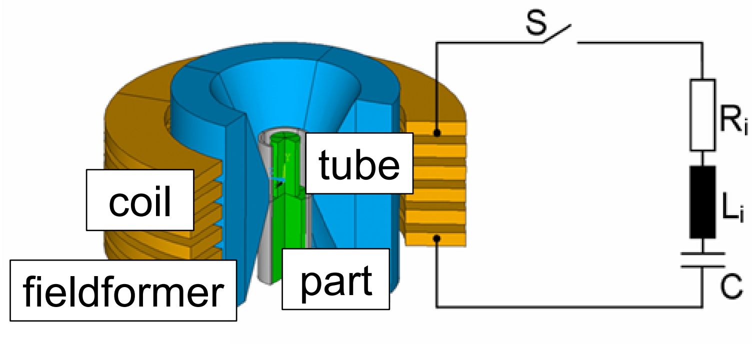
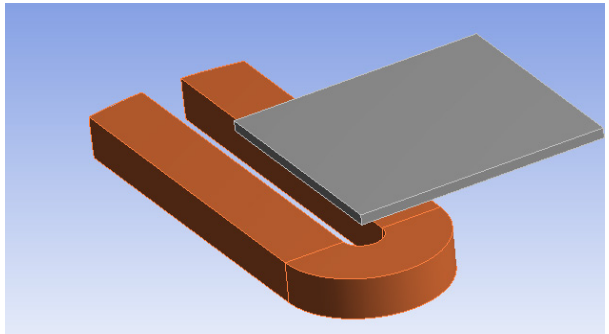
Model Details – Geometry used for Simulations

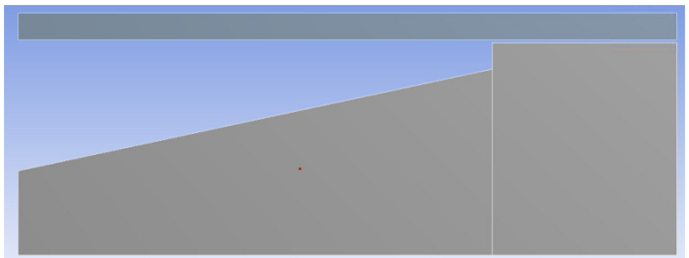
Compression | **Flat Forming**

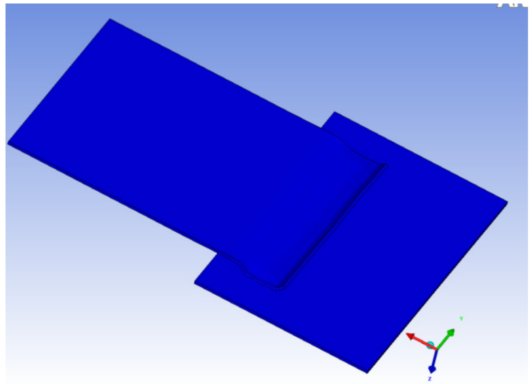
Electromagnetic Geometry





Mechanical Geometry



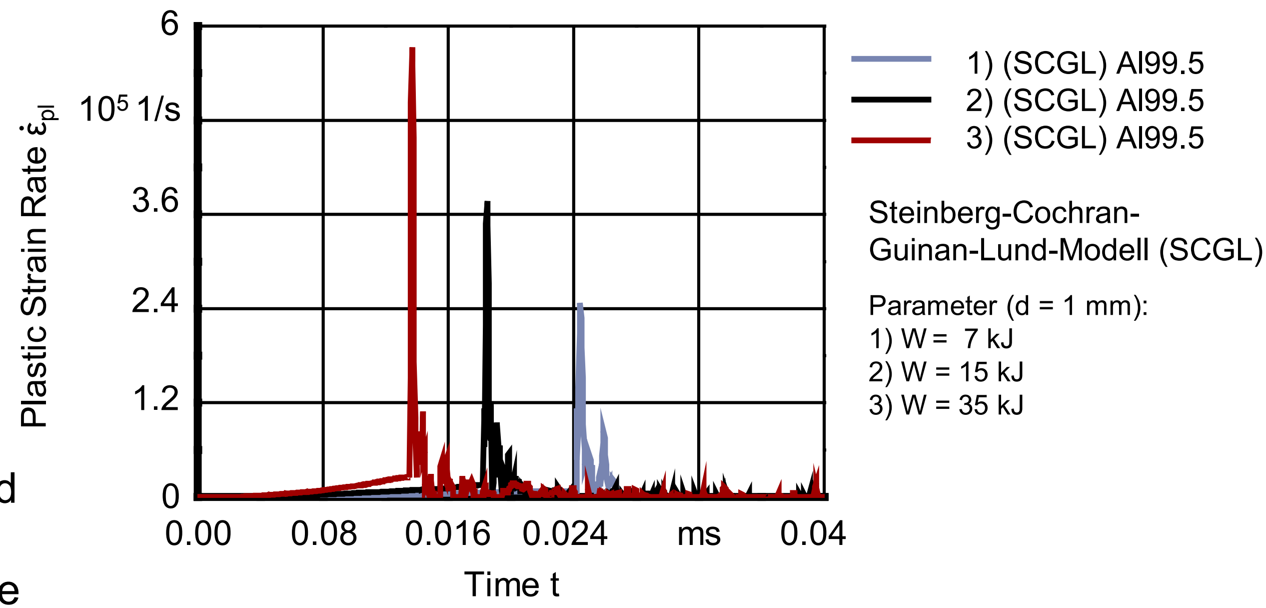


Model Details – explicit Material Model

Process conditions

- Strain rates of ε = 5.5 10^5 1/s
- Pressures of p ≤ 10 GPa
- Process time of t ≤ 500 µs

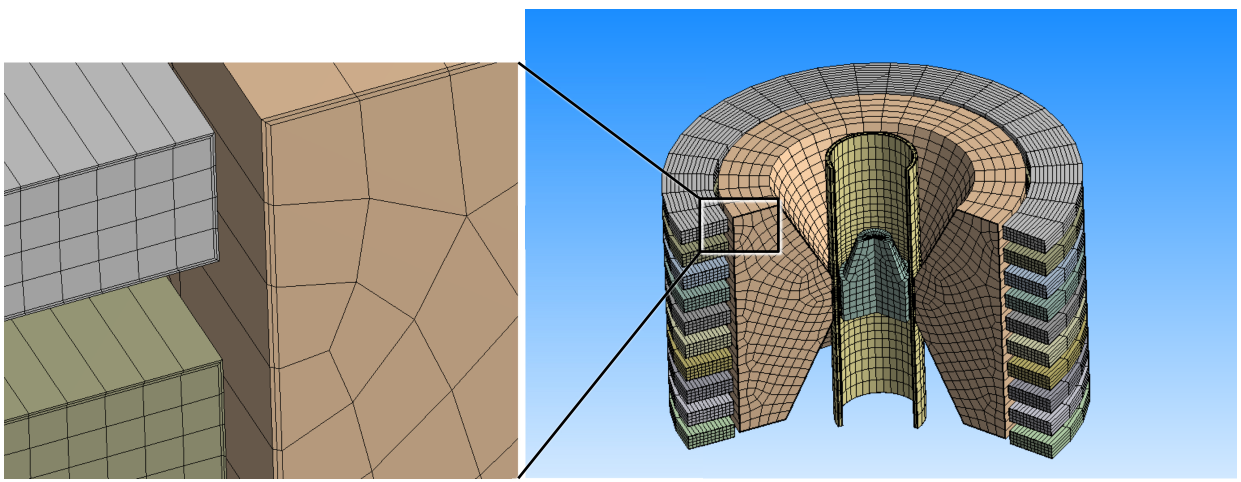
=> Necessity of material model applicable for high strain rates and with Equation of state (EOS) in order to deal with pressures above the yield stress

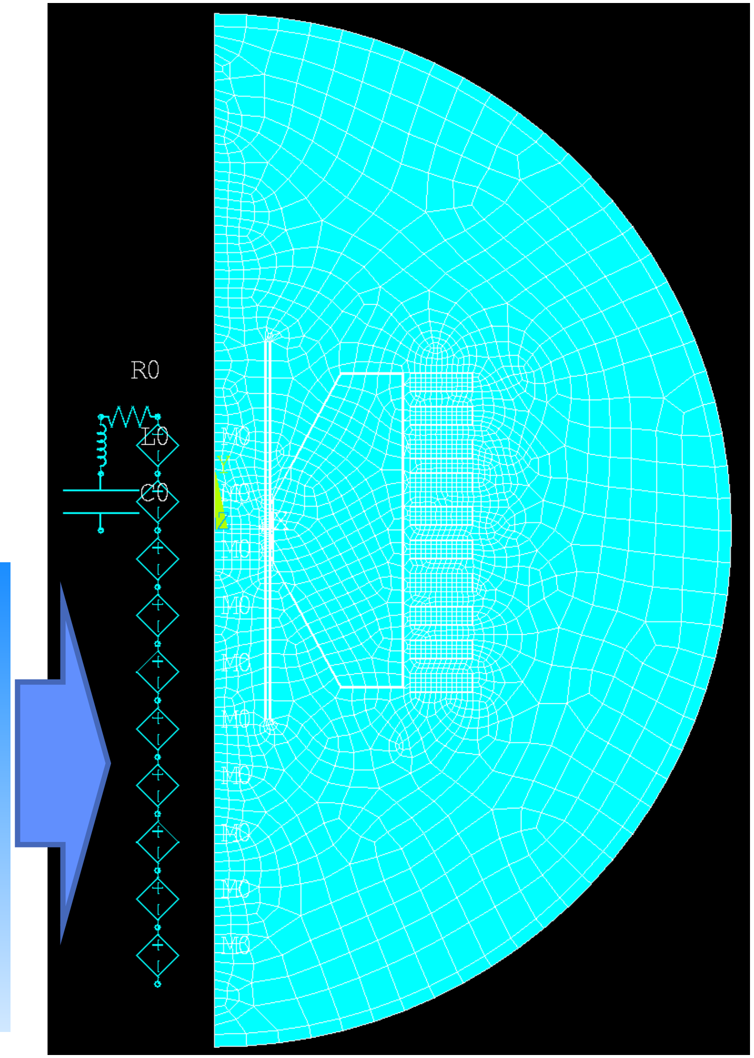


Simulation – Mesh

Electromagnetic Simulation

- To reproduce the skineffect, thin surface layers are needed in electrical conductive parts
- Air domain with infinite boundary
- Bolt geometry inside tube was negelected for elctromagnetic simulation



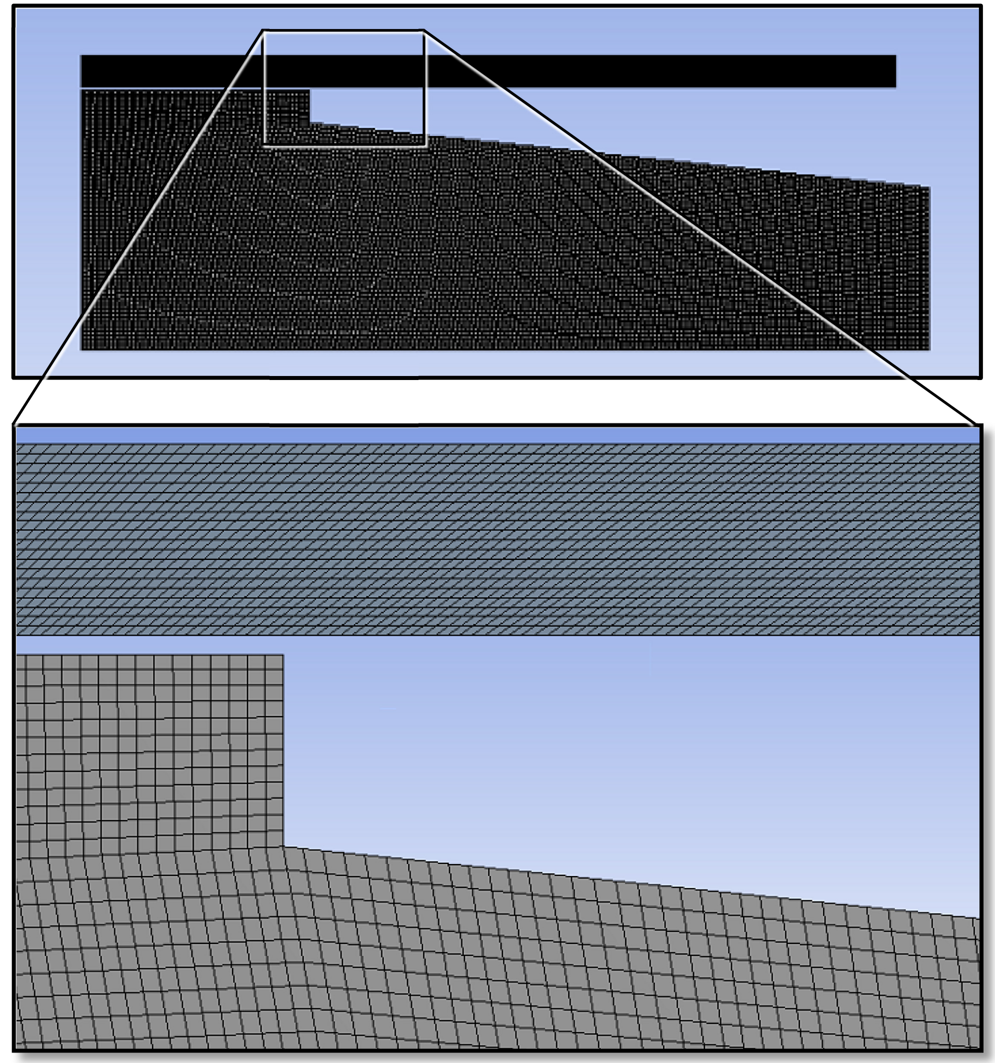


Simulation – Mesh

<u>Explicit structural Simulation</u>

- Aspect ratios of elements close to 1
- Air domain was neglected
- Maximum time step size Δt_{max} is restricted by the minimum cell height Δx_{min}. This relation is described by the courant-condition:

$$\Delta t_{max} \leq \frac{\Delta x_{max}}{c}$$



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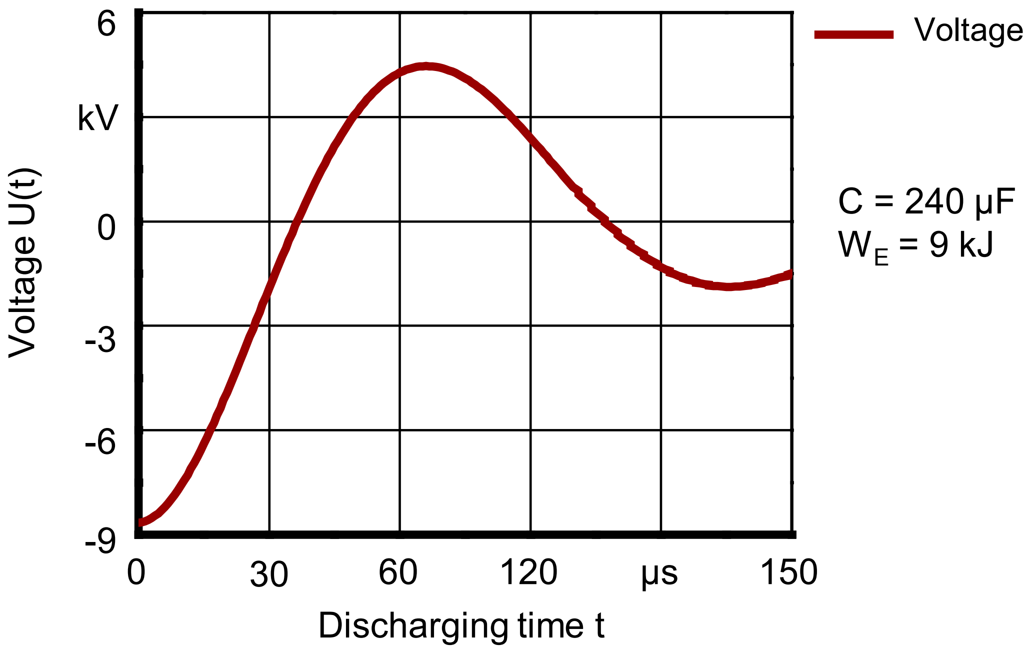
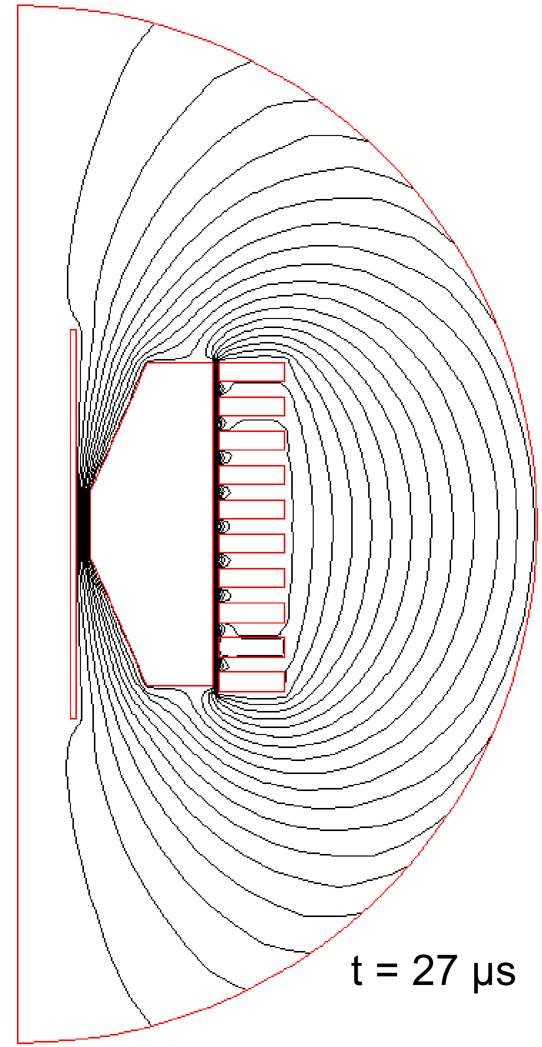
Simulation – Results 2D Case



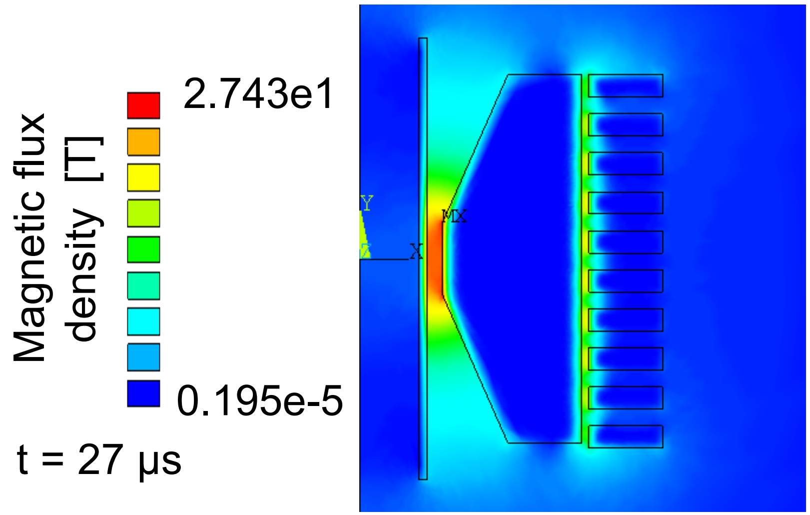
Magnetic Field

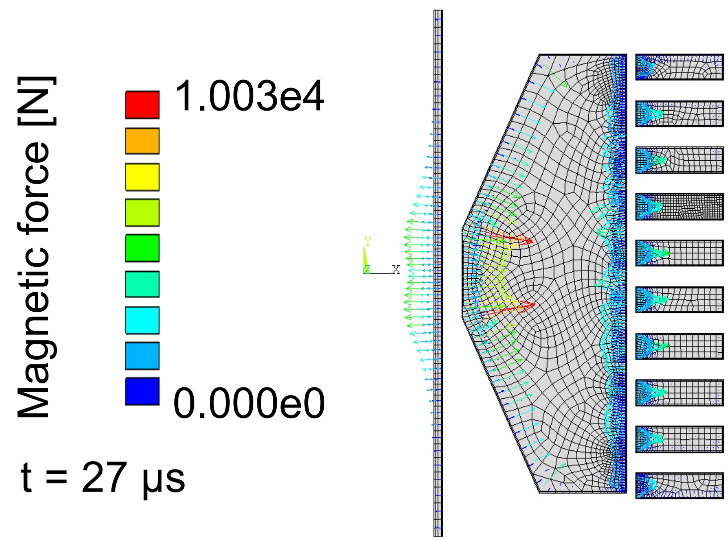


- Voltage development at the capacitor during discharge process

Simulation – Results 2D Case

- Magnetic forces F_{mag} were stored in data file
- Current I and voltage V of discharge circuit were validated with measurements
- Magnetic flux density component parallel to the tool coil axis (B_y) was validated with measurements
- Process forces inside the tool coil as well as the field former can be evaluated





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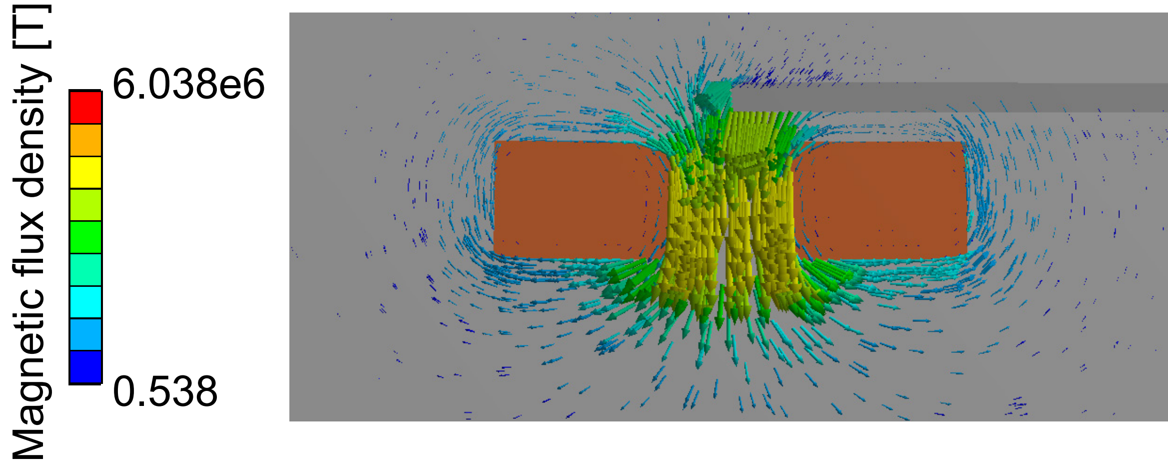
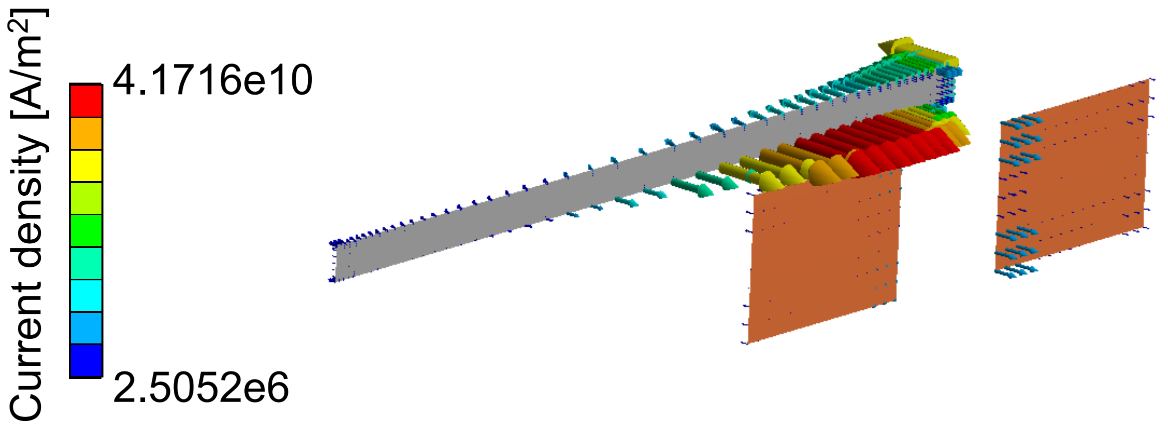
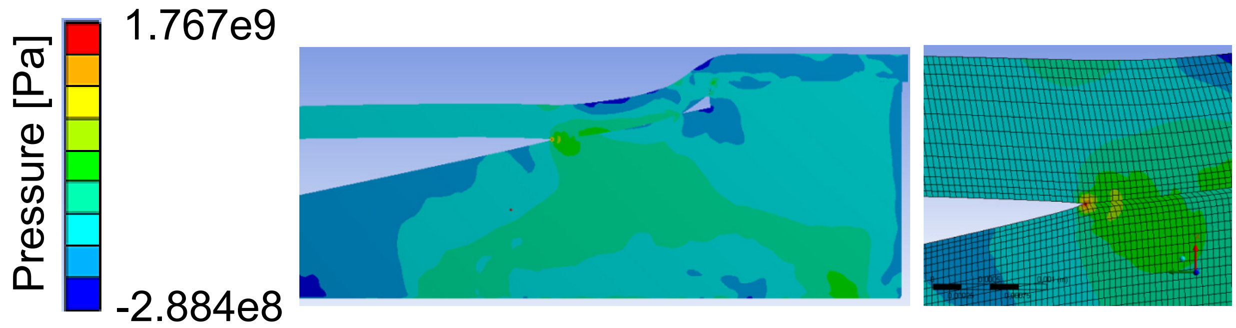
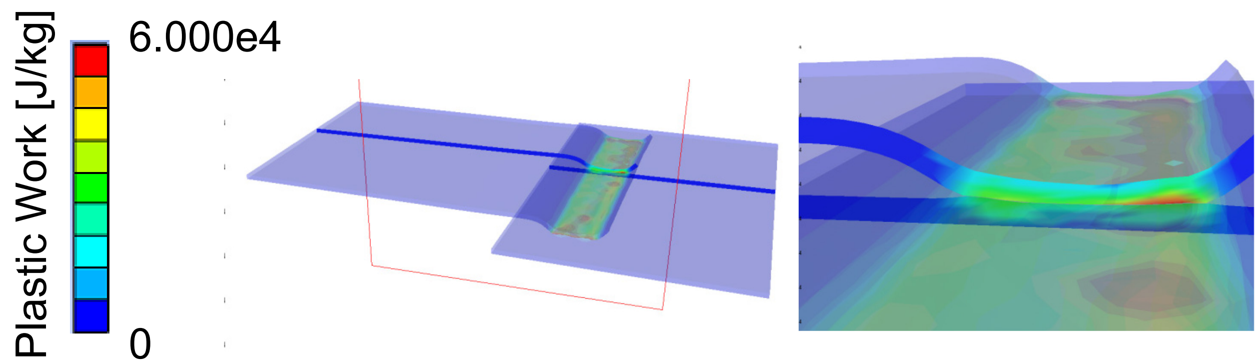




Results

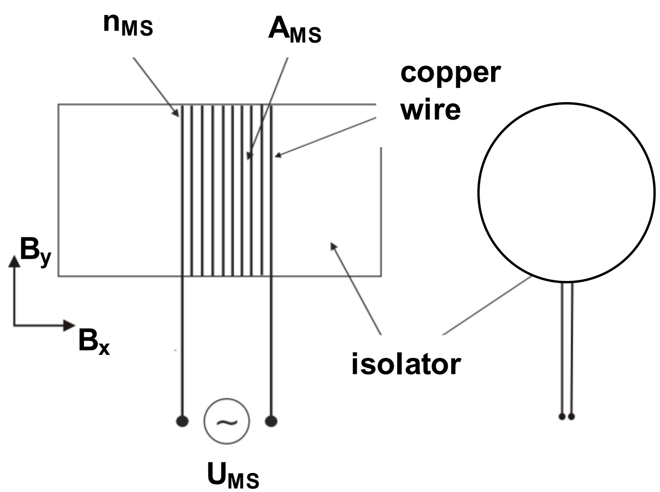
- Propagation of the shock wave is shown
- Plastic deformation at the surface can be used as welding criterium
- Better insights in strain hardening effects and deformation of the joint
- Result can be further processed for stress analysis

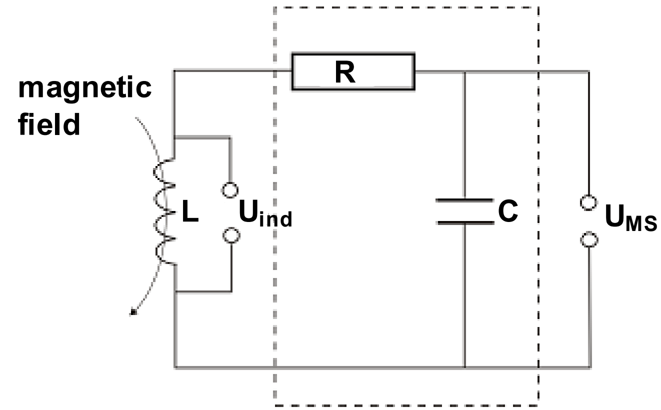




Validation – magnetic Flux Density

- Measurement of maximum magnetic flux density $B_{y,\,max}$
- Measurements were carried out with calibrated hall sensor as well as self-applied flat wound measurement coil
- Qualification of the discharge current with rogowski coil





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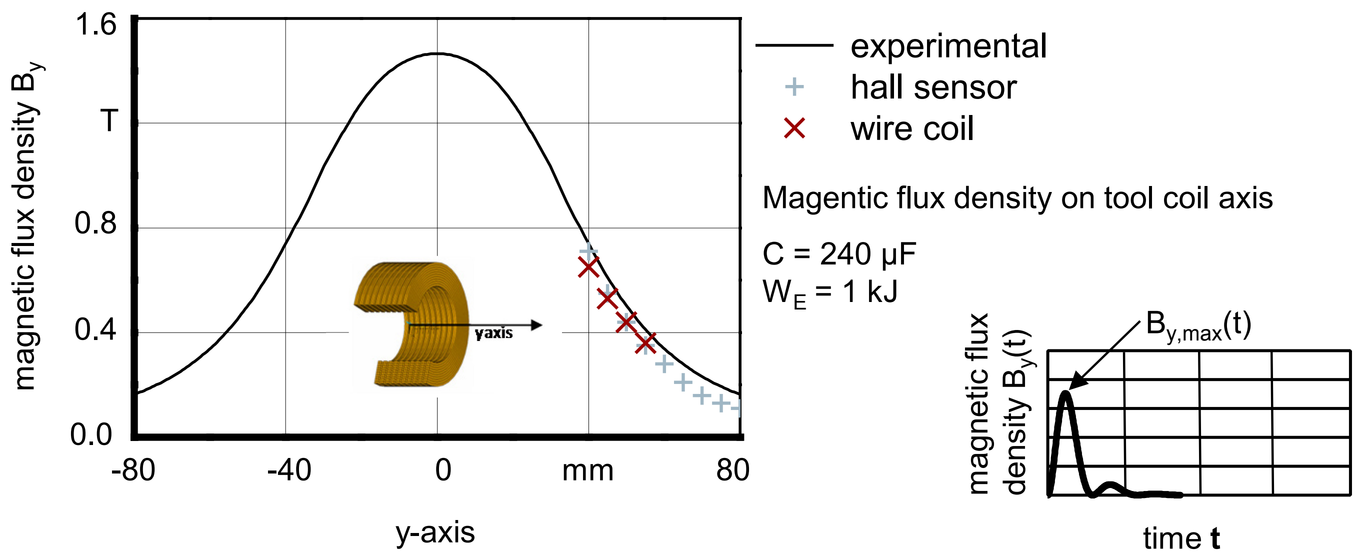


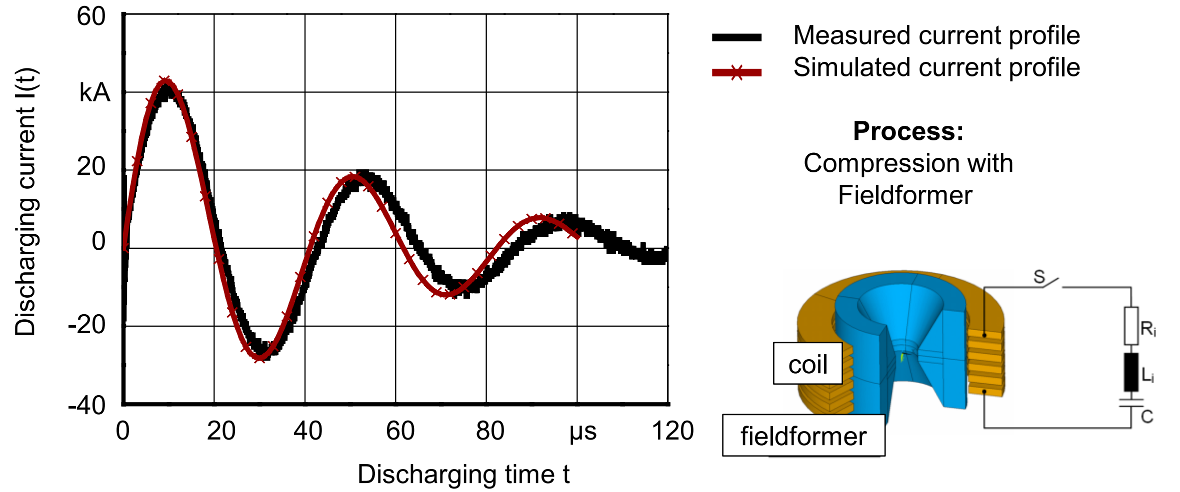
Validation – Discharge Current

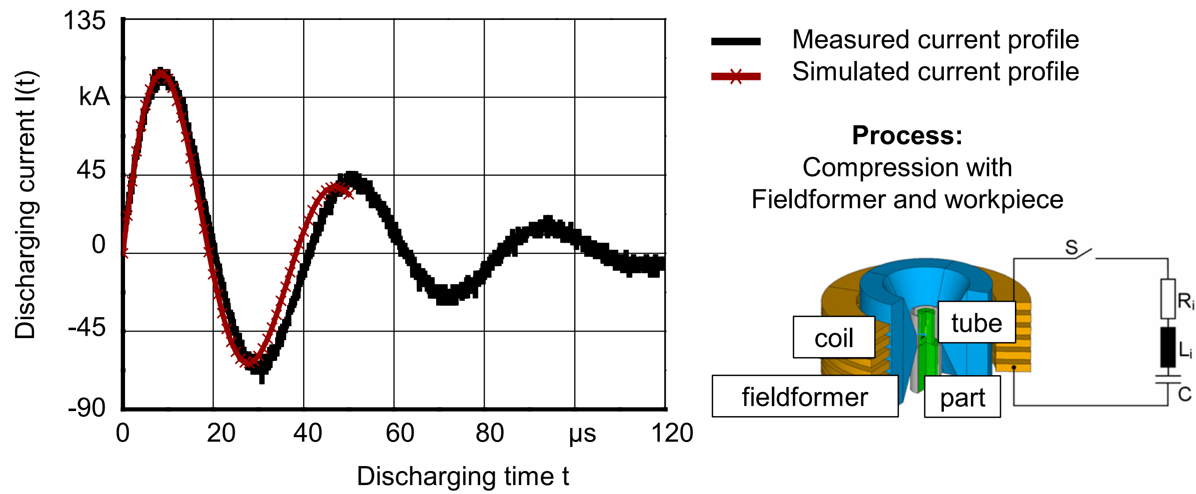
- Discharge current was measured by use of a rogowski coil

$$I(t) = m\, U_{rog}(t)$$

- Increasing distance between workpiece and field former during the deformation -> change of the mutual inductance

- Amplitude as well as frequency show good agreement for both cases





Conclusion

- Pulse magnetic forming machine was modelled as equivalent discharge FEM circuit, whereas the tool coil and the work piece are modelled as FEM model
- Good qualitative and quantitative assessment of the inherent physical processes enabling to conduct an optimisation of geometry
- Pressure as well as the calculated plastic work are important process indicators and can eventually be used as welding criterion
- Simulations were validated with magnetic flux density measurements as well as current measurements

Thank you very much for your attention!

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