Modelling Magnetic Pulse Crimping

Workshop Impulse Forming & Joining
2013/05/07

Patrick Goes OCAS NV

OCAS: a joint venture between
ArcelorMittal and the Flemish Region

OCAS
ArcelorMittal – Flemish Region

Site Zelzate
Pres. J. F. Kennedylaan 3
B-9060 Zelzate
BELGIUM

Site Zwijnaarde
Technologiepark 903B and 935
B-9052 Zwijnaarde
BELGIUM

+ 32 9 345 12 11
services@ocas.be
www.ocas.be

OCAS combines strengths

MATERIALS RESEARCH CLUSTER GENT

- Materials Research Cluster
- Initiative with CRM, BIL, Sirris, Flamac, SIM, Clusta, Ghent University

MSC
METAL STRUCTURES CENTRE

- Metal Structures Centre
- Initiative with Belgian Welding Institute (BIL) and Ghent universities' lab Soete

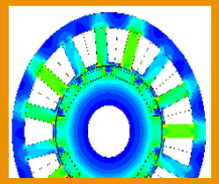
MPC
Metal Processing Centre Gent

- Metal Processing Centre
- Joint venture with Centre for Research in Metallurgy (CRM)

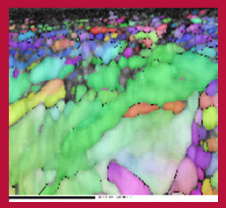
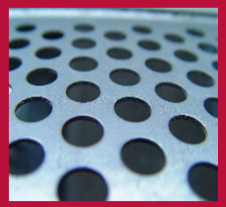
OCAS

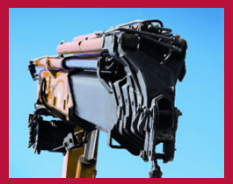
Energy



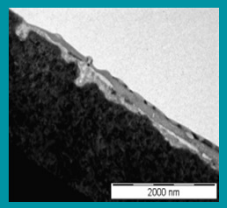
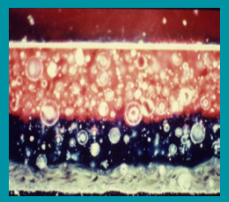



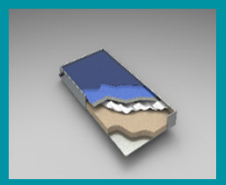
Durability

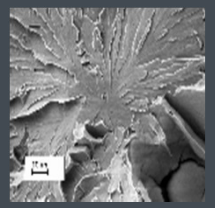


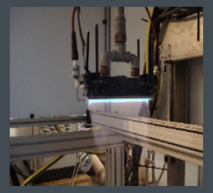
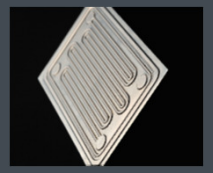
Environment



Technical Support & Entrepreneurial R&D



Metallurgy

Surfaces

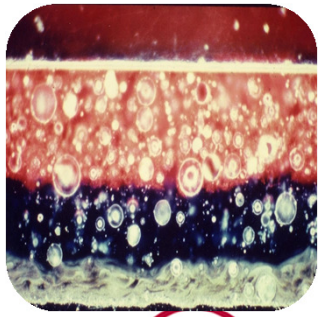
Applications & Solutions

Metallurgy

- **Extending product range of ultra high strength steels**
  - ✓ Pearlitic-bainitic-martensitic multiphase grades
  - ✓ Improving hydrogen embrittlement resistance of steel
  - ✓ Optimising hydrogen induced cracking corrosion (HIC) properties
- **Innovative developments for specific applications**
  - ✓ Low loss high permeability electrical steel
  - ✓ Green alternative for direct white enamelling

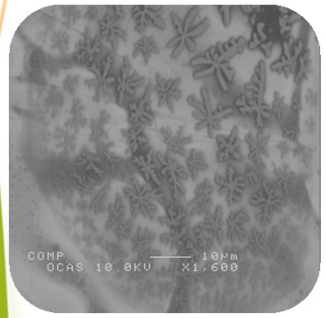


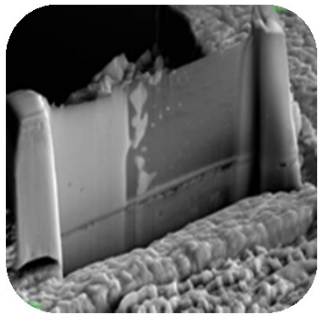


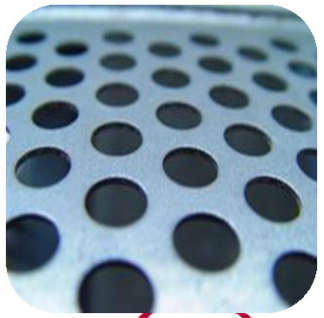


Surfaces

- **Extend durability of metallic coatings**
  - ✓ Mg in metallic coating for long lasting corrosion protection
  - ✓ Wear resistance coatings
- **Develop cost-effective REACH compliant passivation products**
  - ✓ CrVI-free passivations
  - ✓ Ready-to-paint, Ready-to-enamel, Dry lubes
- **Add novel functionalities to coatings**
  - ✓ Organic, metallic & hybrid coatings

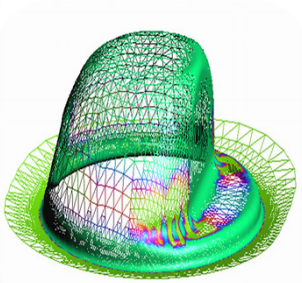
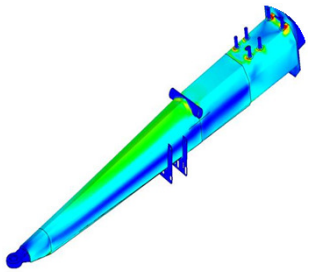




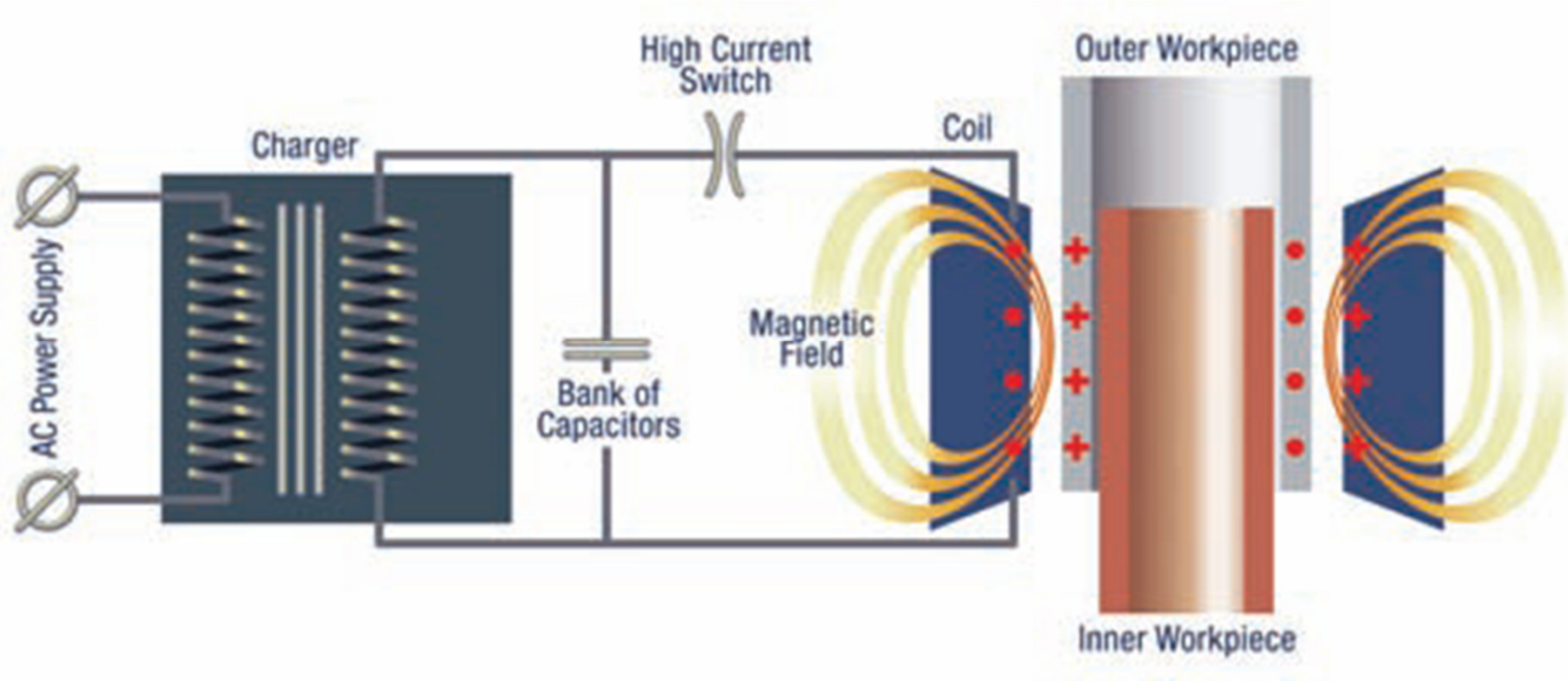
Applications & solutions

- **Product implementation based on finite element simulations**
  - ✓ Co-design & Co-engineering with manufacturer
- **Applied research**
  - ✓ New solution concepts
  - ✓ Communication kits
- **Numerical simulation and validation using real test set-up**

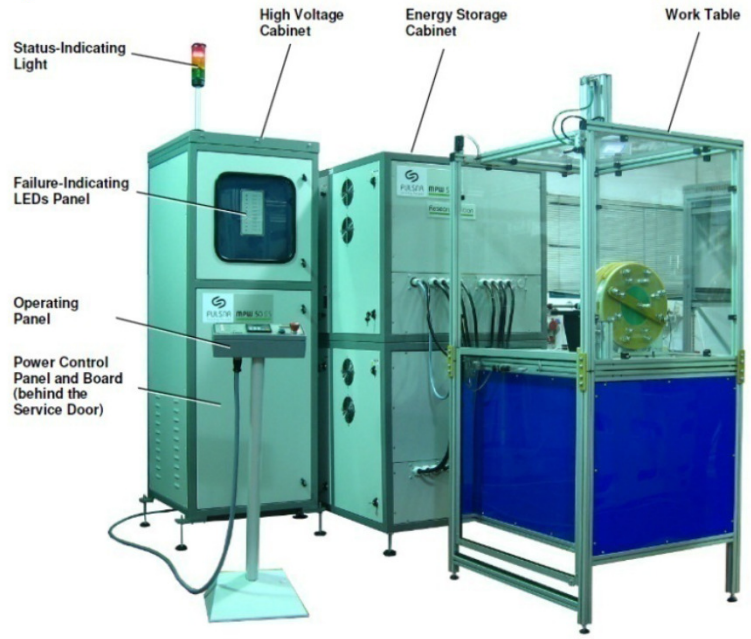



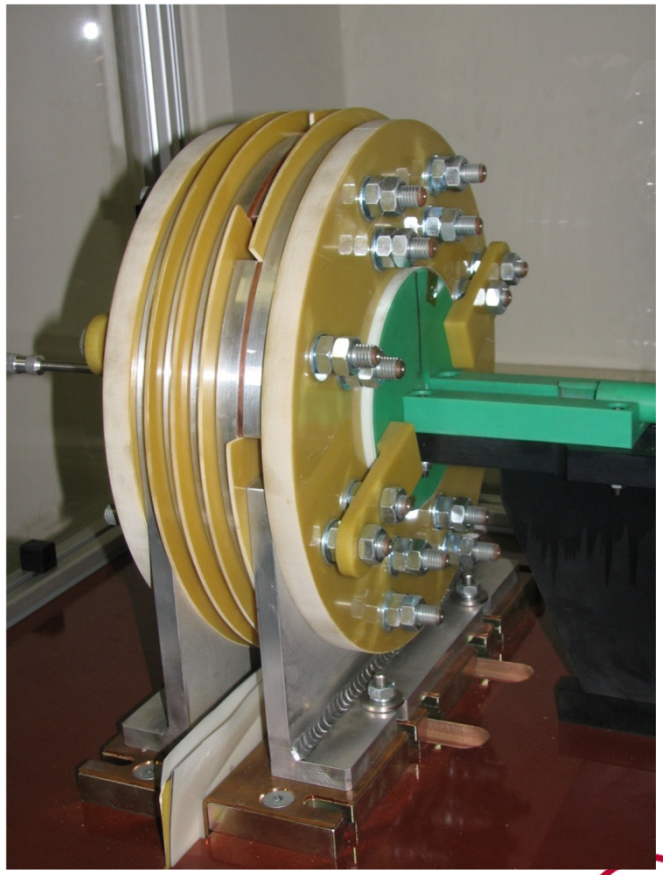

- What is Magnetic Pulse Crimping?
- What needs to be modelled?

Operating Principle



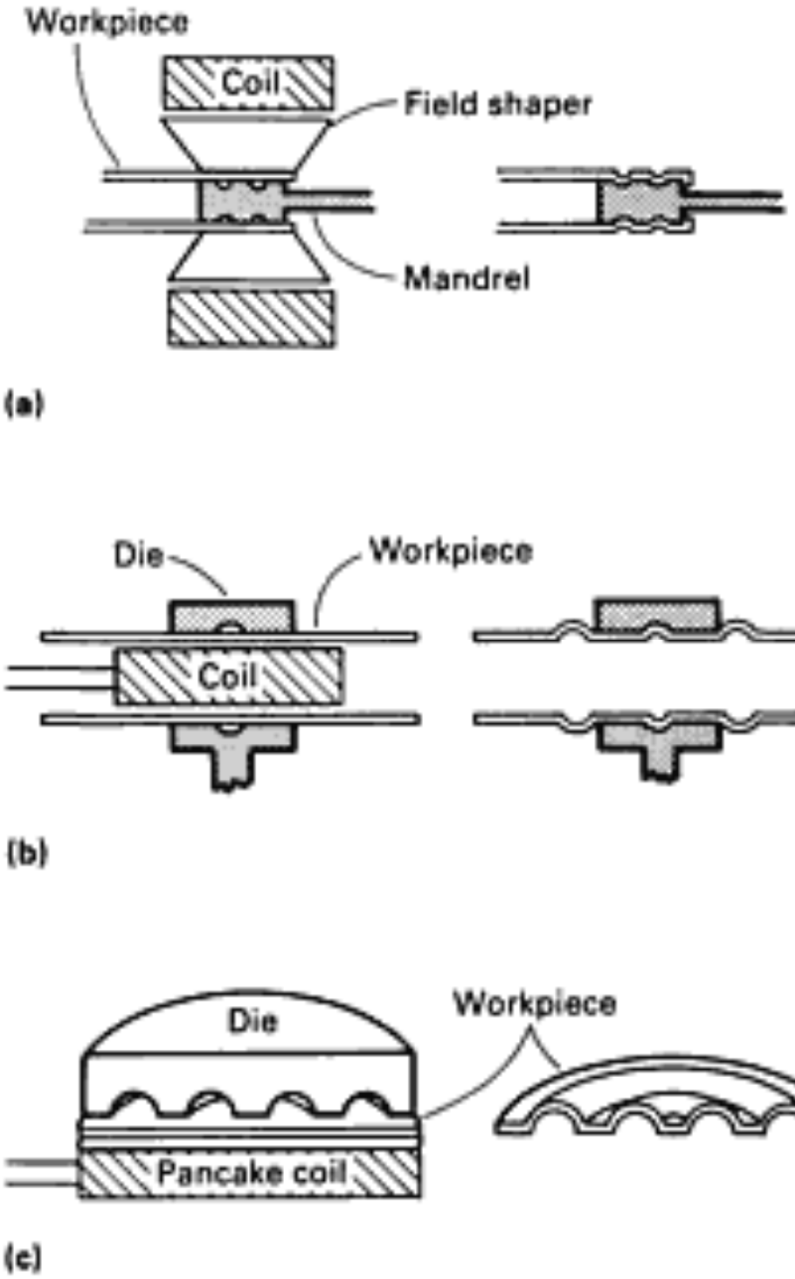
Equipment @ BIL (Pulsar 50kJ / 25kV)



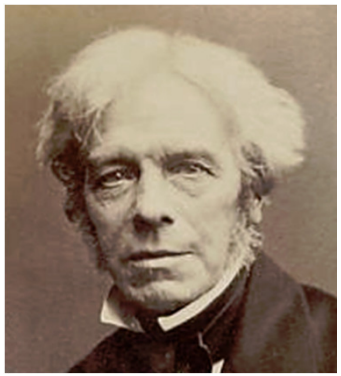


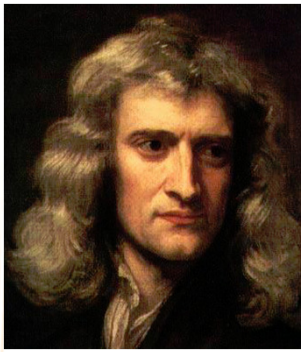
Applications

- Tube compression
- Tube expansion
- Sheet metal forming



Electro magnetics



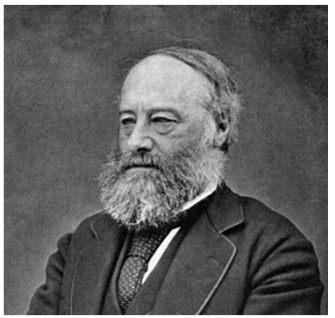


Currents

PulsCrimp Physics

Forces

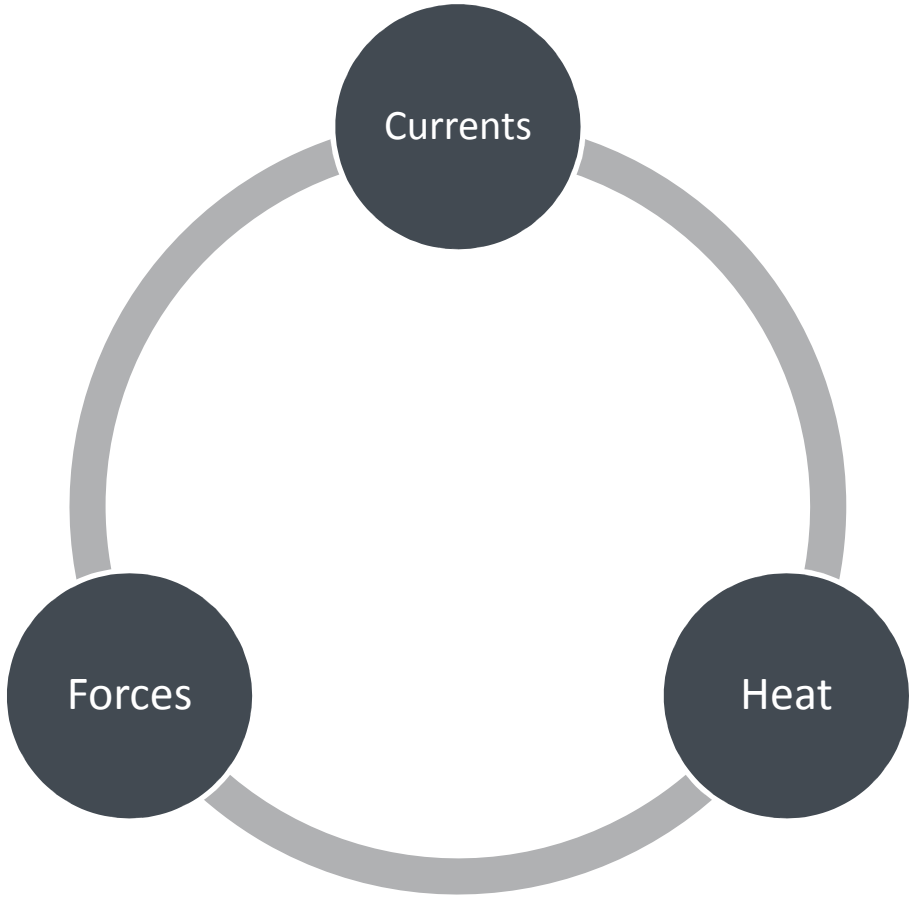
Heat



Mechanics

Heat transport

Electro magnetics

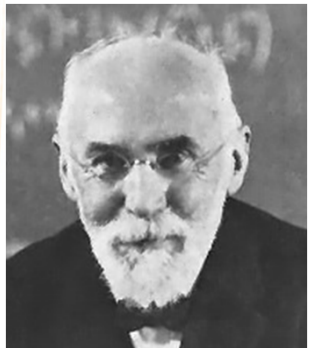


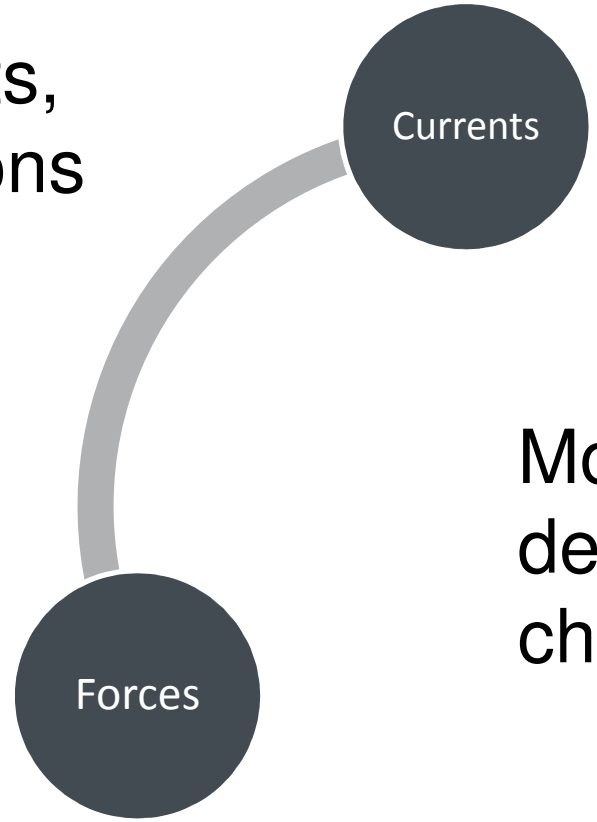
Mechanics

Heat transport

Electro magnetics

Currents cause forces, movements, deformations





Movements and deformations cause change in currents

Mechanics

Plastic deformation causes heating

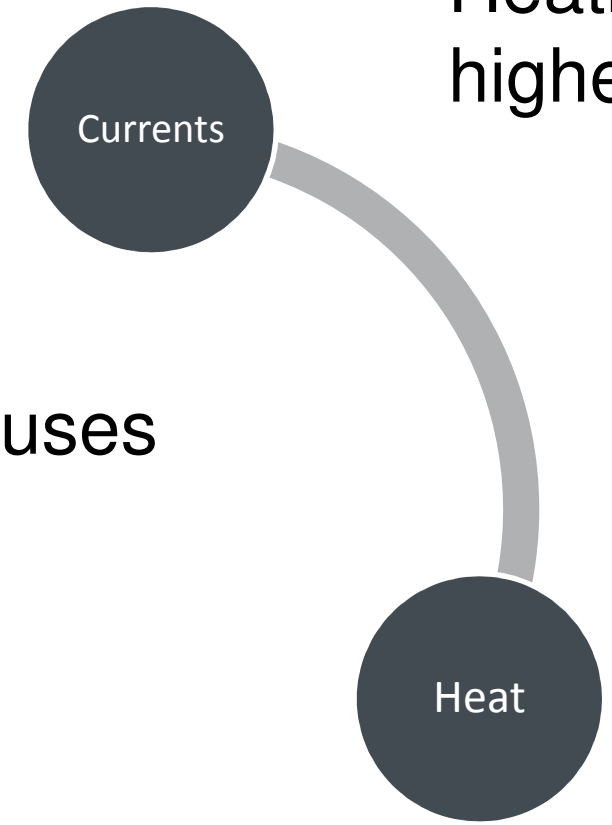
Heating causes softening

Mechanics

Heat transport

Electro magnetics

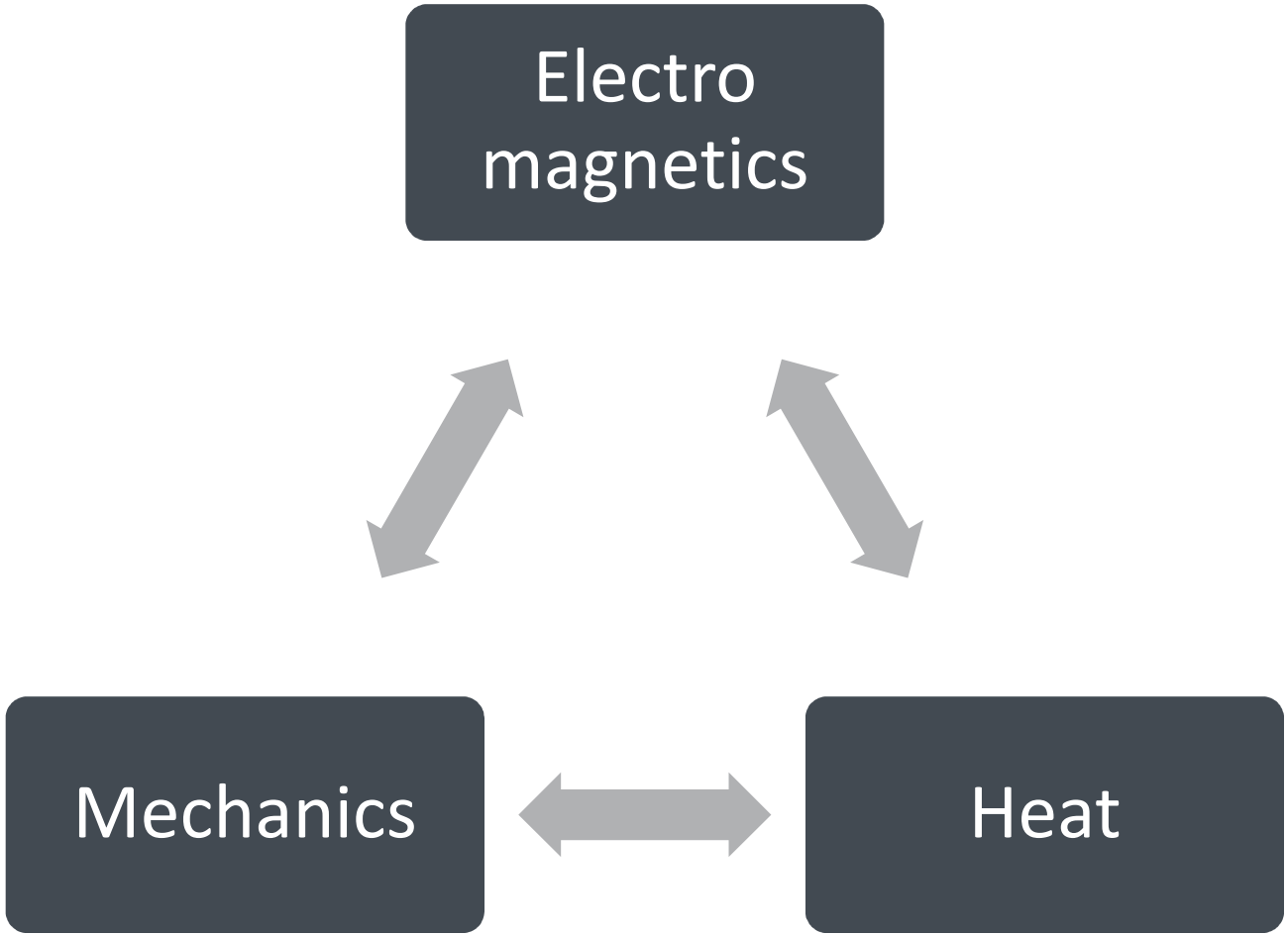
Heating causes higher resistance



current causes heating

Heat transport

Coupled multiphysics



Purpose of modelling

- **ElectroMagnetic Forming is complex: many relevant material and process parameters**
  - ✓ Material of work piece
    - ElectroMagnetic properties: σ (or ρ), μ
    - Mechanical properties
      - Elastic: E, ν
      - Plastic: σ_y, hardening
      - Viscoplastic: strain rate dependency, damping
    - Thermal properties: Cp, (k)
  - ✓ Process
    - Geometry
      - Coil
      - Field shaper
      - Work piece
      - Mandrel
    - Electrical (Uo, C)
- **Reduce needs for experiments**

Challenges of modelling

- **Multiphysics**
  - ✓ Electric circuit (Kichhoff)
  - ✓ ElectroMagnetic induction (Faraday)
  - ✓ Plasticity (von Mises)
  - ✓ Dynamics (Newton)
  - ✓ Electric heating (Joule)
  - ✓ Plastic work heating (Taylor-Quinney)
- **Interactions**
  - ✓ EM – Mech
  - ✓ EM – Therm
  - ✓ Mech – Therm
- **Highly nonlinear !**

Simulation tools

- Pre-2005: academic codes
- Now: commercial multiphysics
  - ✓ Comsol
  - ✓ ANSYS
- MagPuls (2008-2009) – Comsol 3.5
- PulsCrimp (2011-2012) – Comsol 4.2, now 4.3a

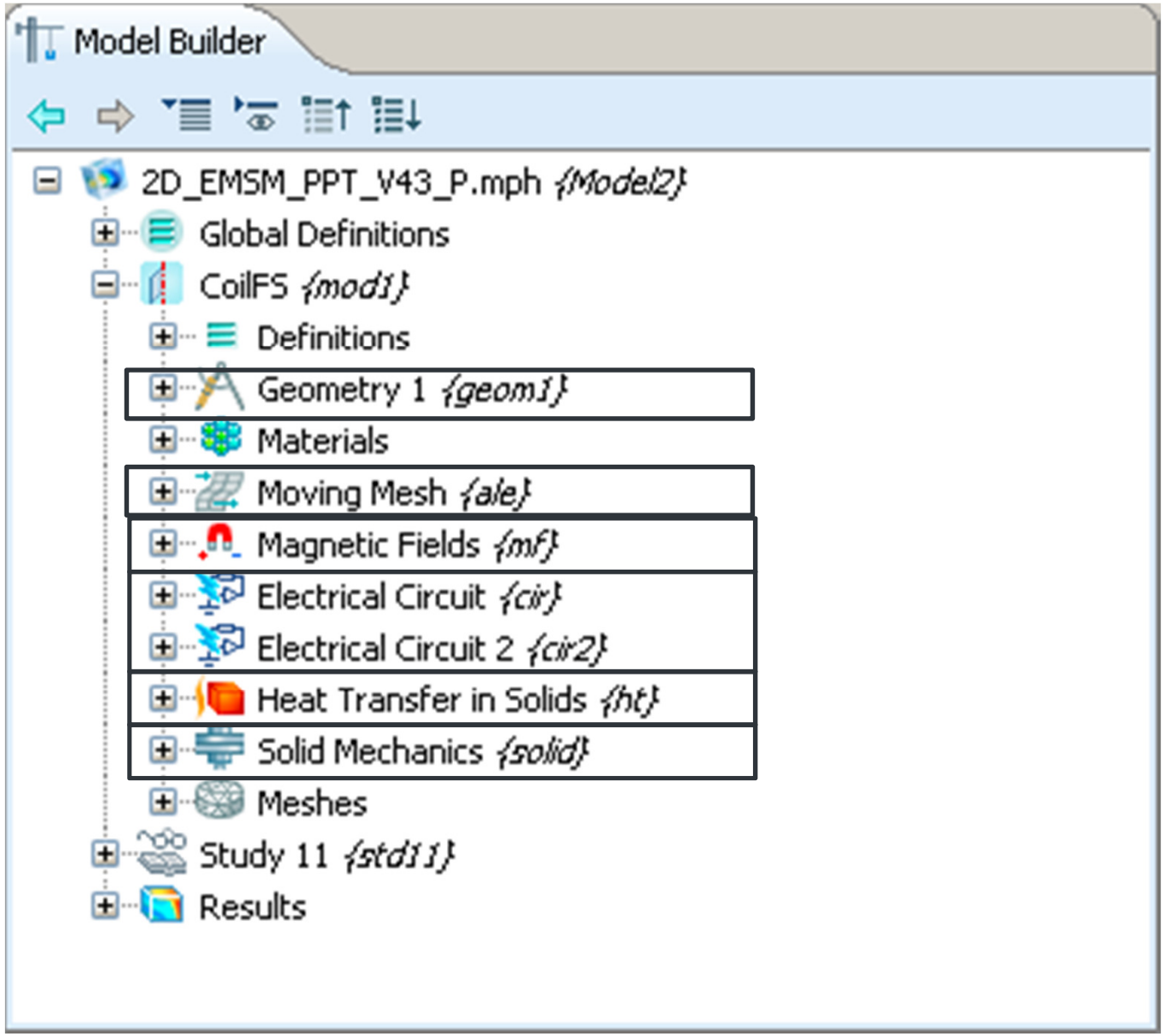
- New needs – new capabilities

New needs for PulsCrimp

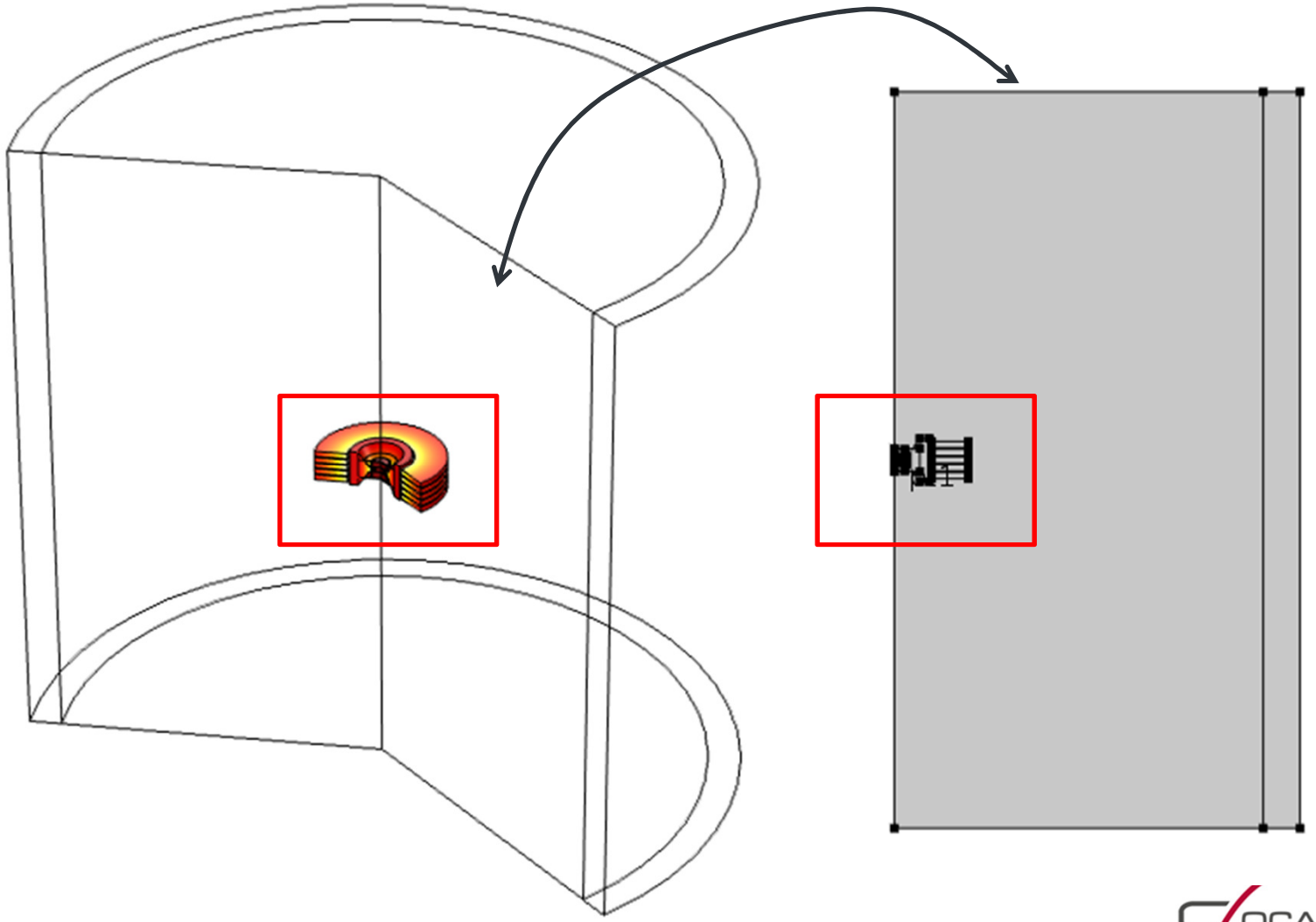
- **Large deformations**
  - ✓ Strong influence of deformation on EM solution
- **Contact**
  - ✓ More complex mandrel geometry
- **Stresses in coil and field shaper**

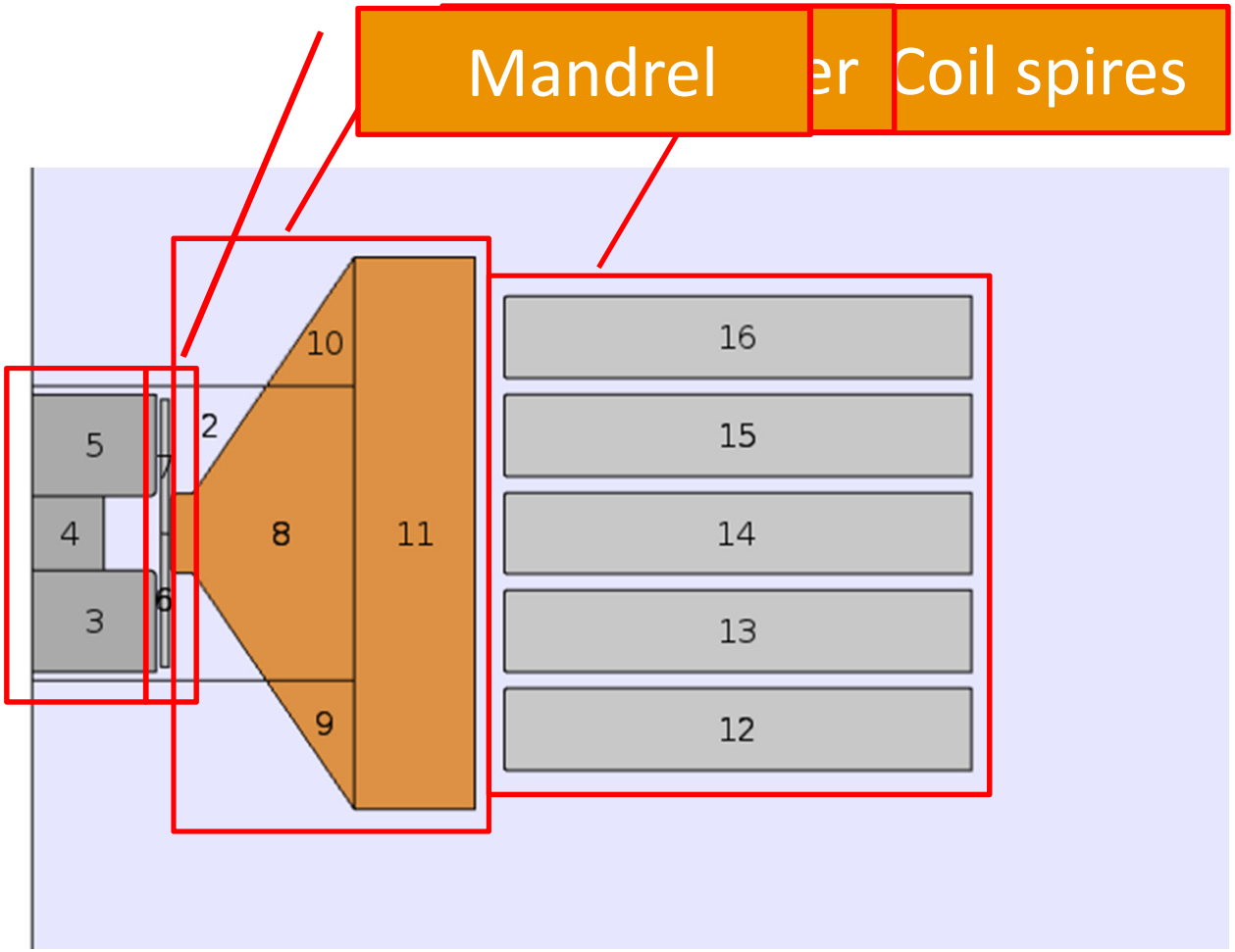
New capabilities

- **Electric circuit – EM solver**
- **Moving mesh in gaps**
  - ✓ between field shaper and work piece
  - ✓ Between work piece and mandrel
- **Automatic remeshing**
  - ✓ In gaps
  - ✓ Near contact
- **Better computing hardware**

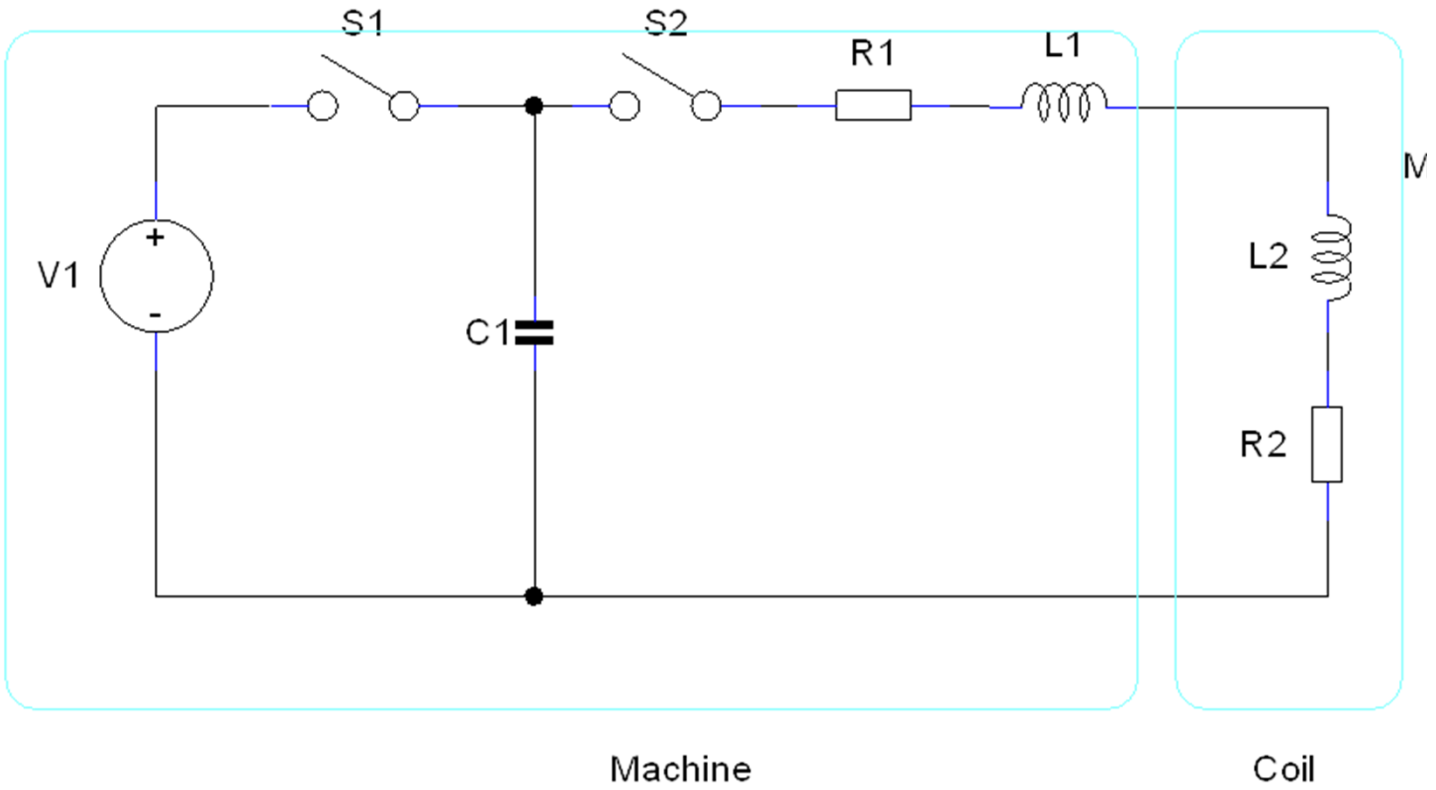


Geometry: 2D Axisymmetrical

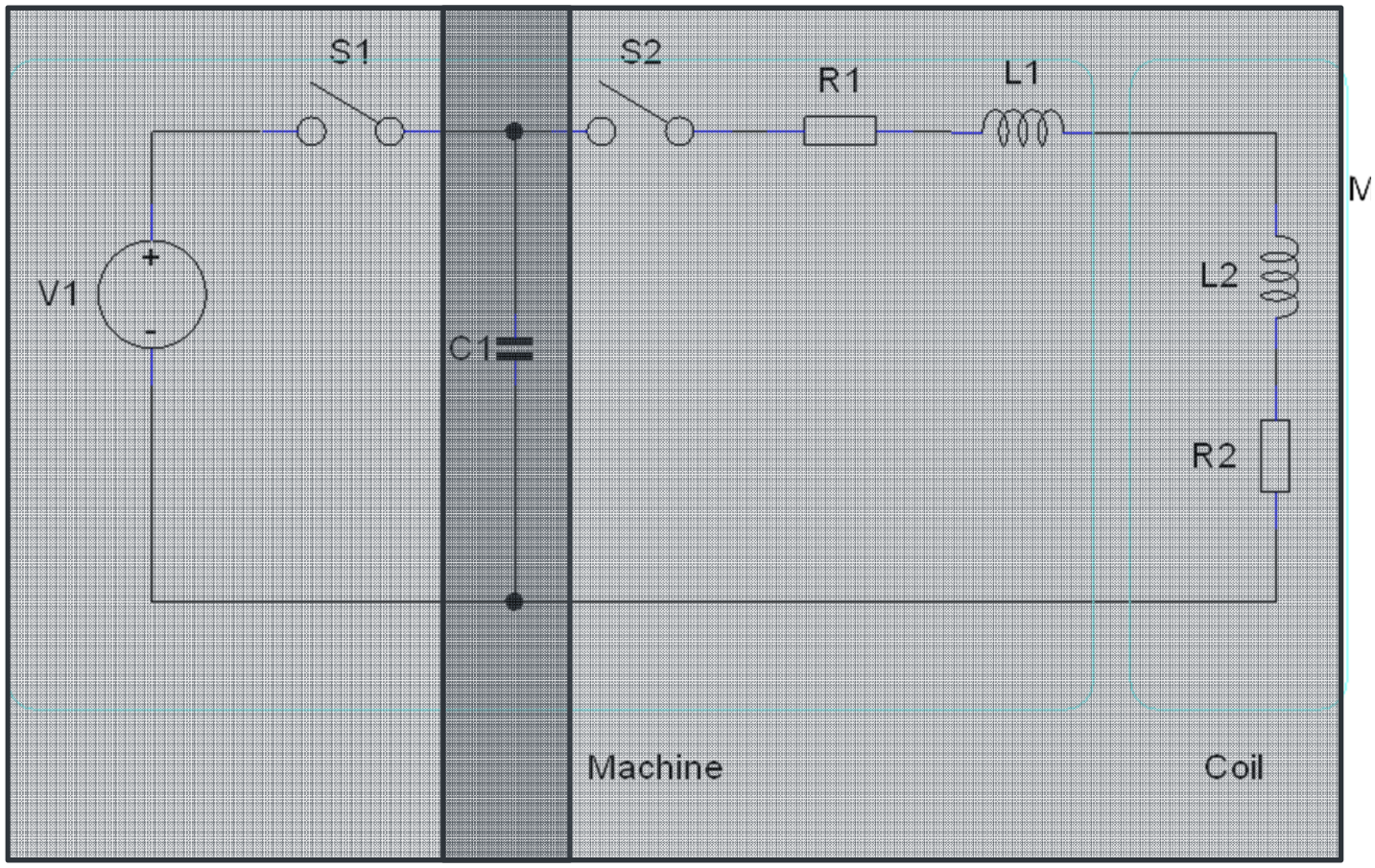




Lumped circuit – Finite Element

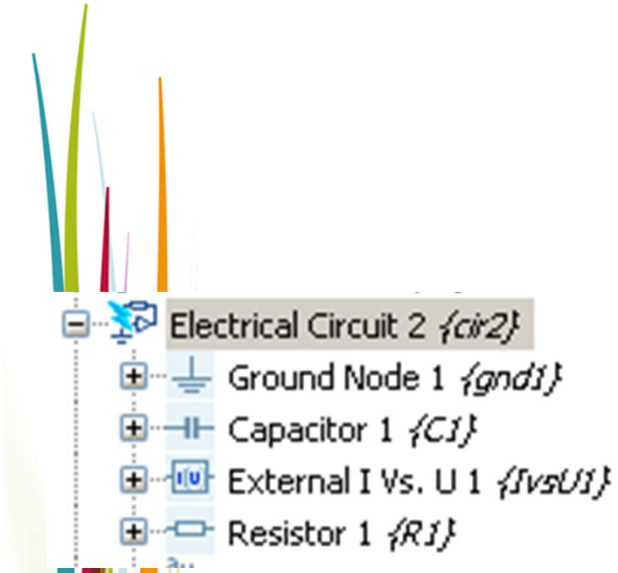


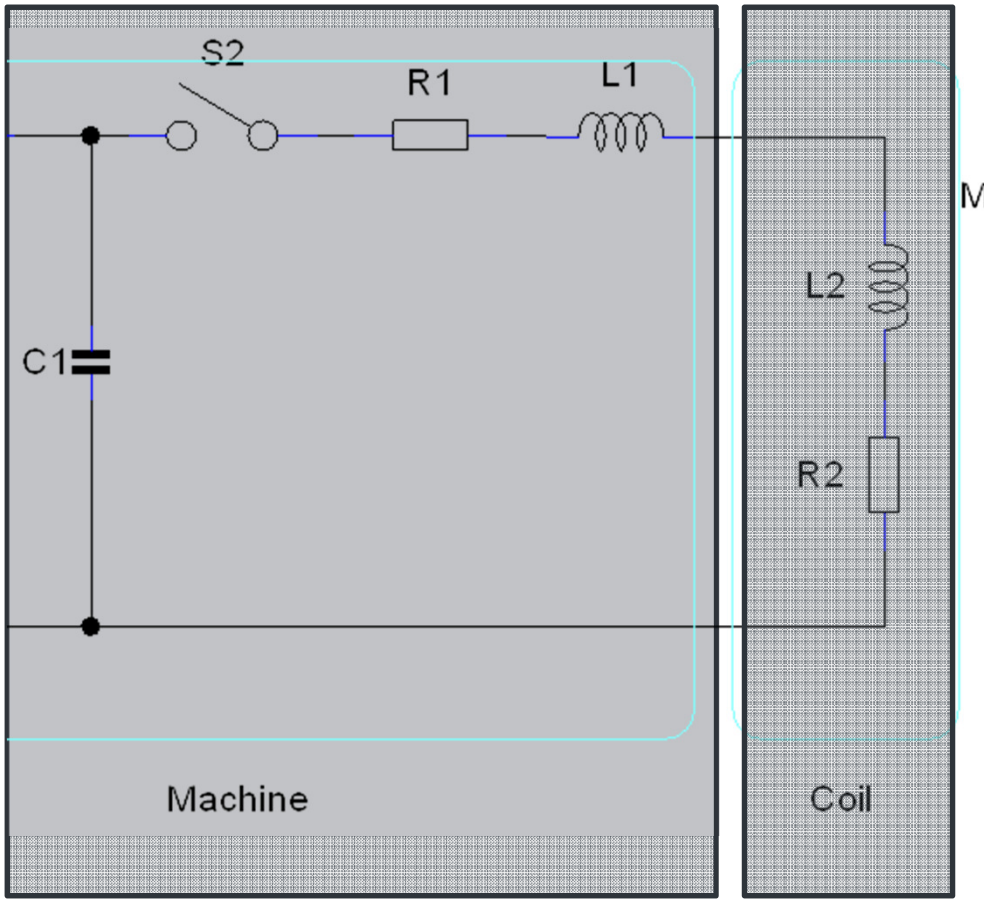
Lumped circuit – Finite Element



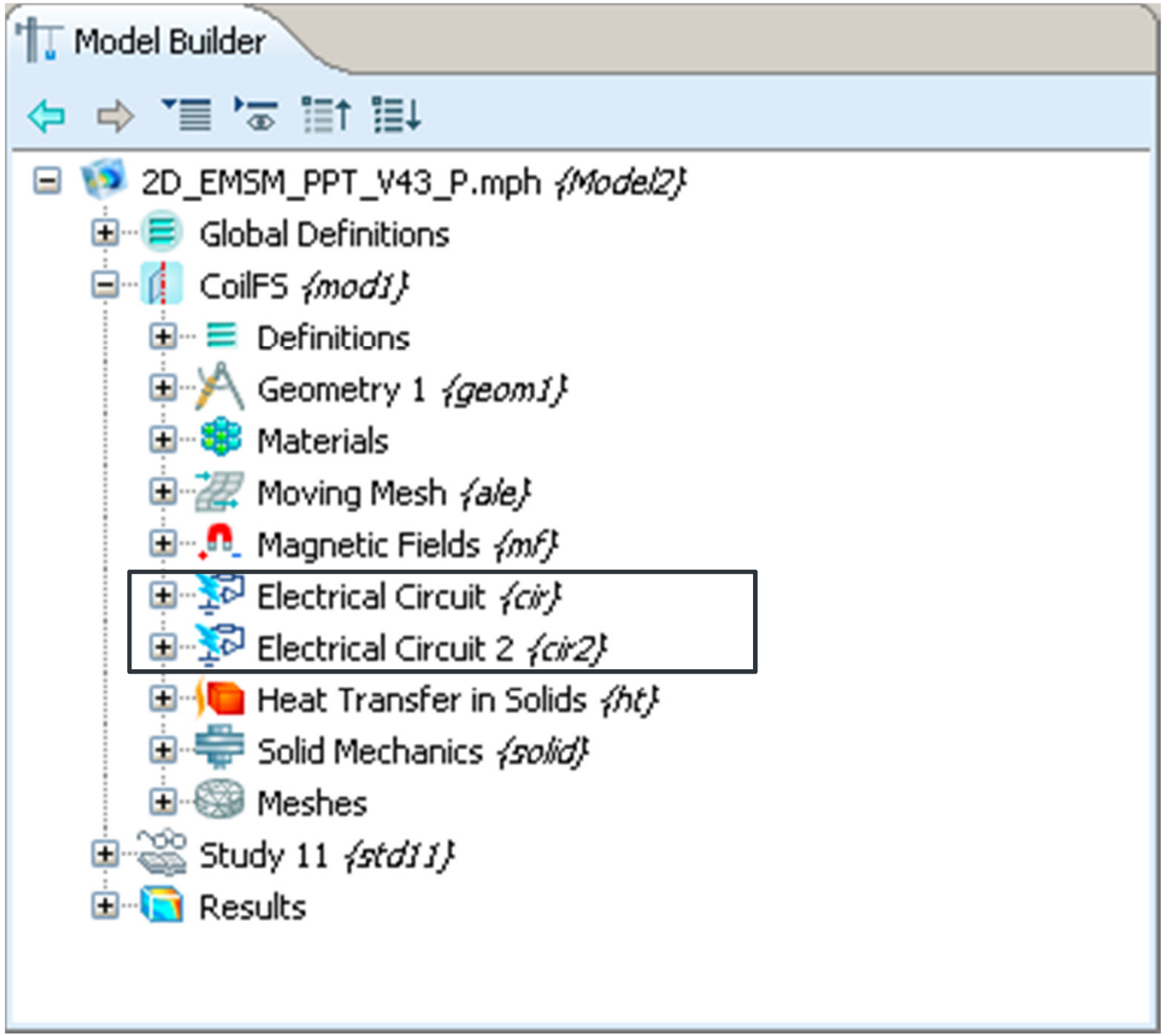
Charging circuit Discharging circuit

Lumped circuit – Finite Element

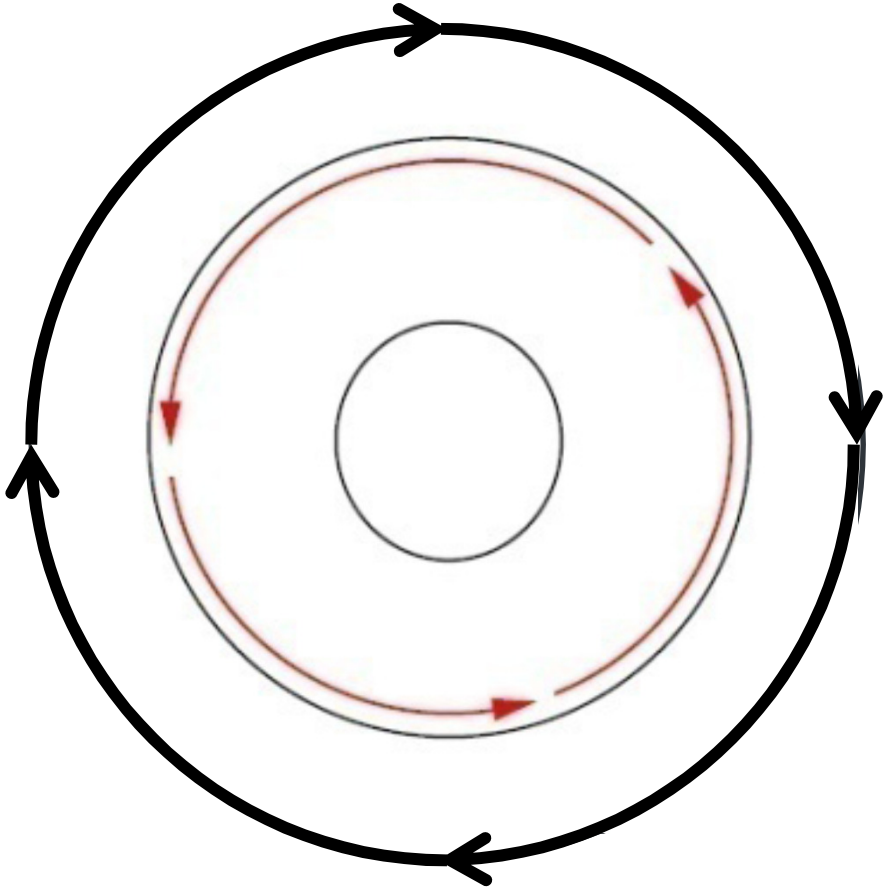




Lumped circuit Finite Element Model

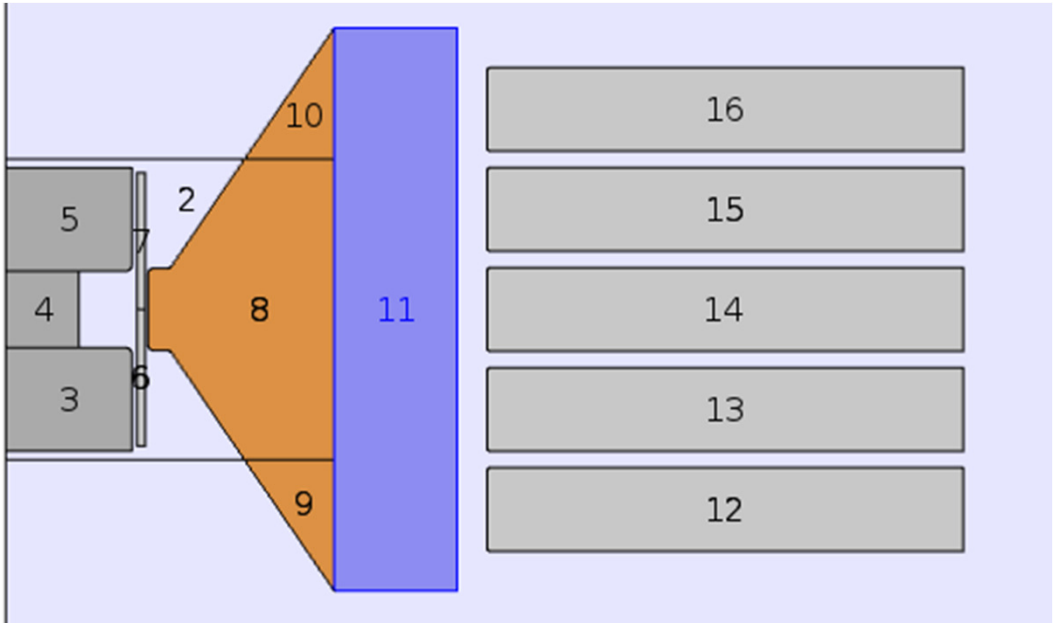


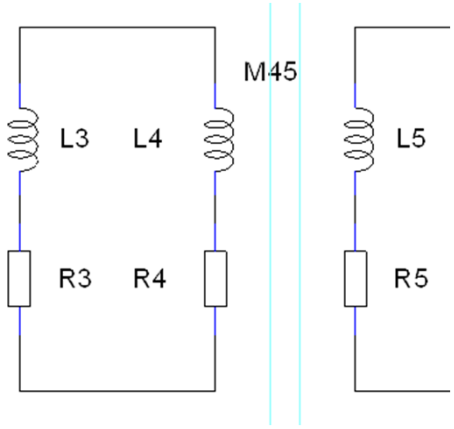
Coil and Field Shaper seen from top



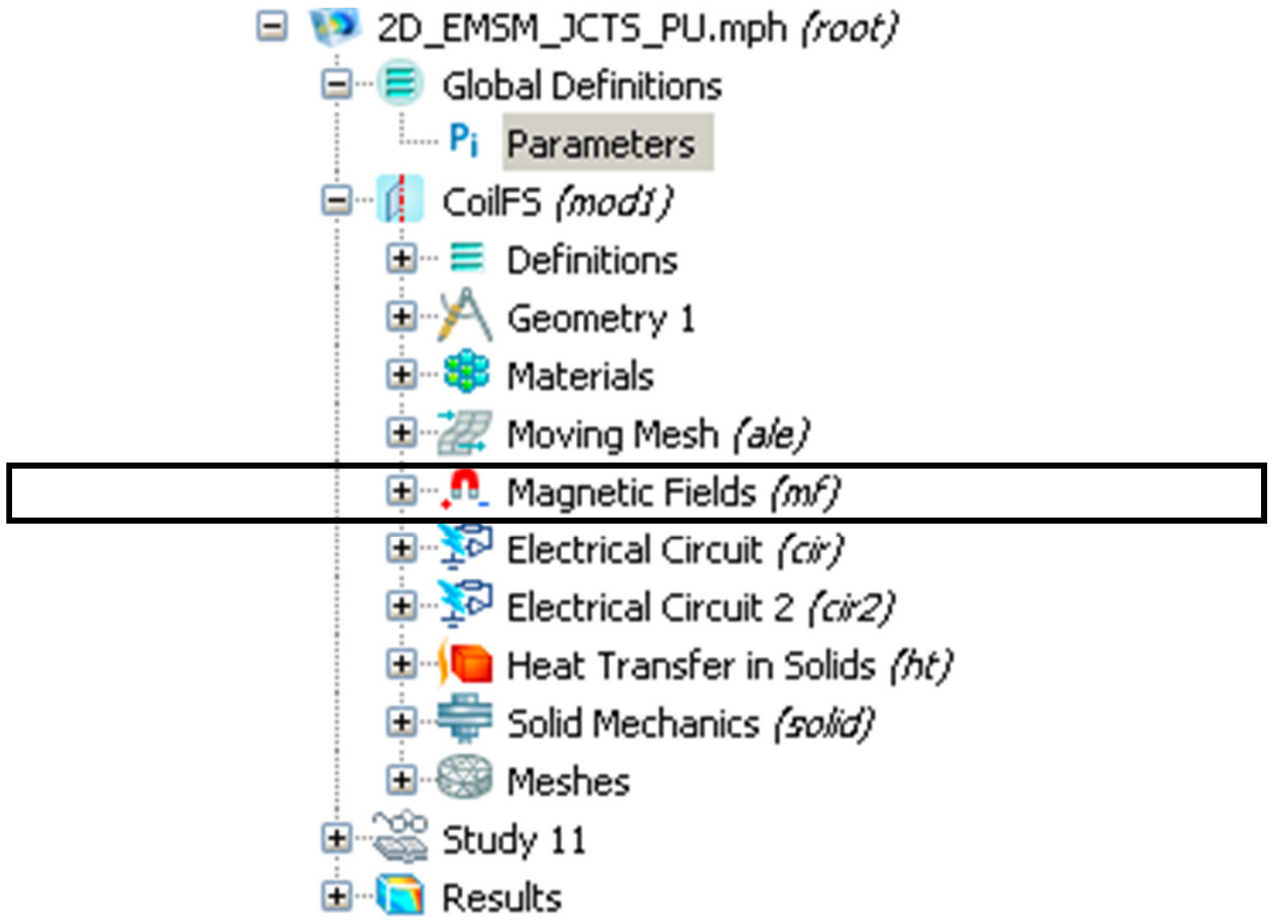
Slit in field shaper :
no longer Axisymmetrical

Divided field shaper with circuit

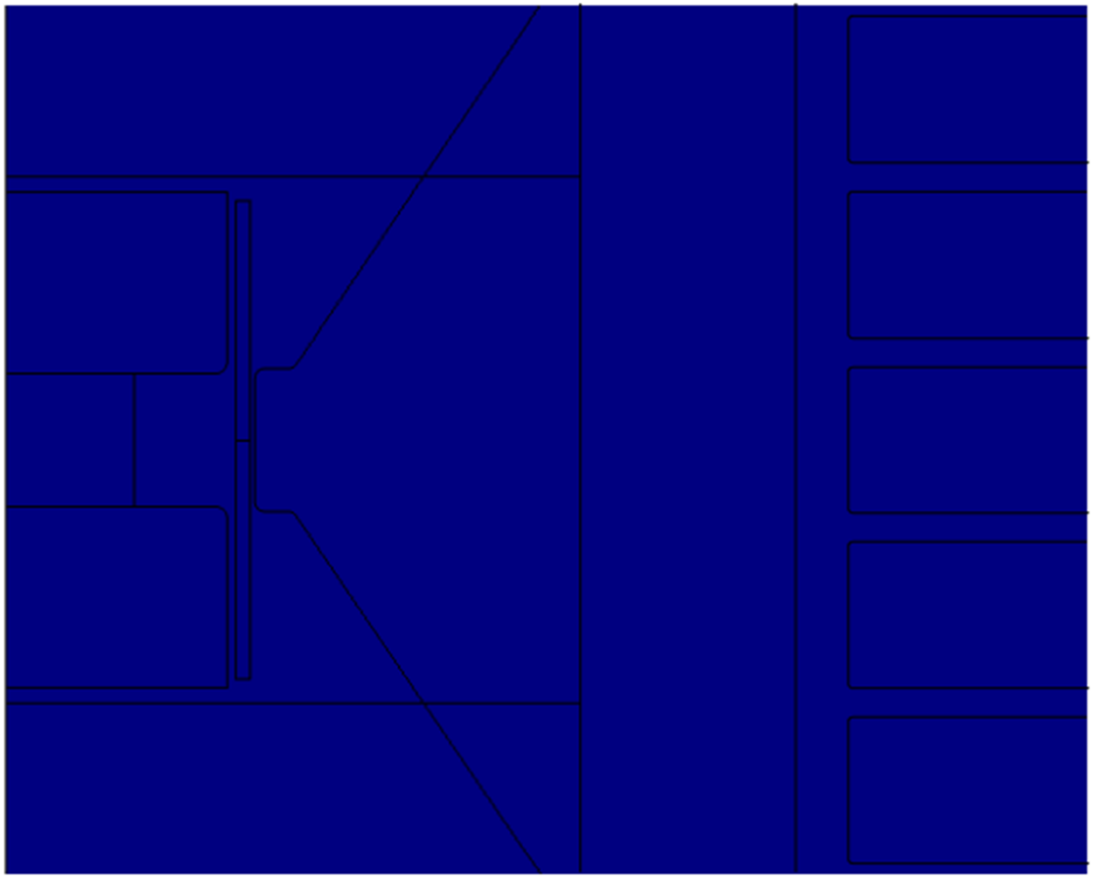




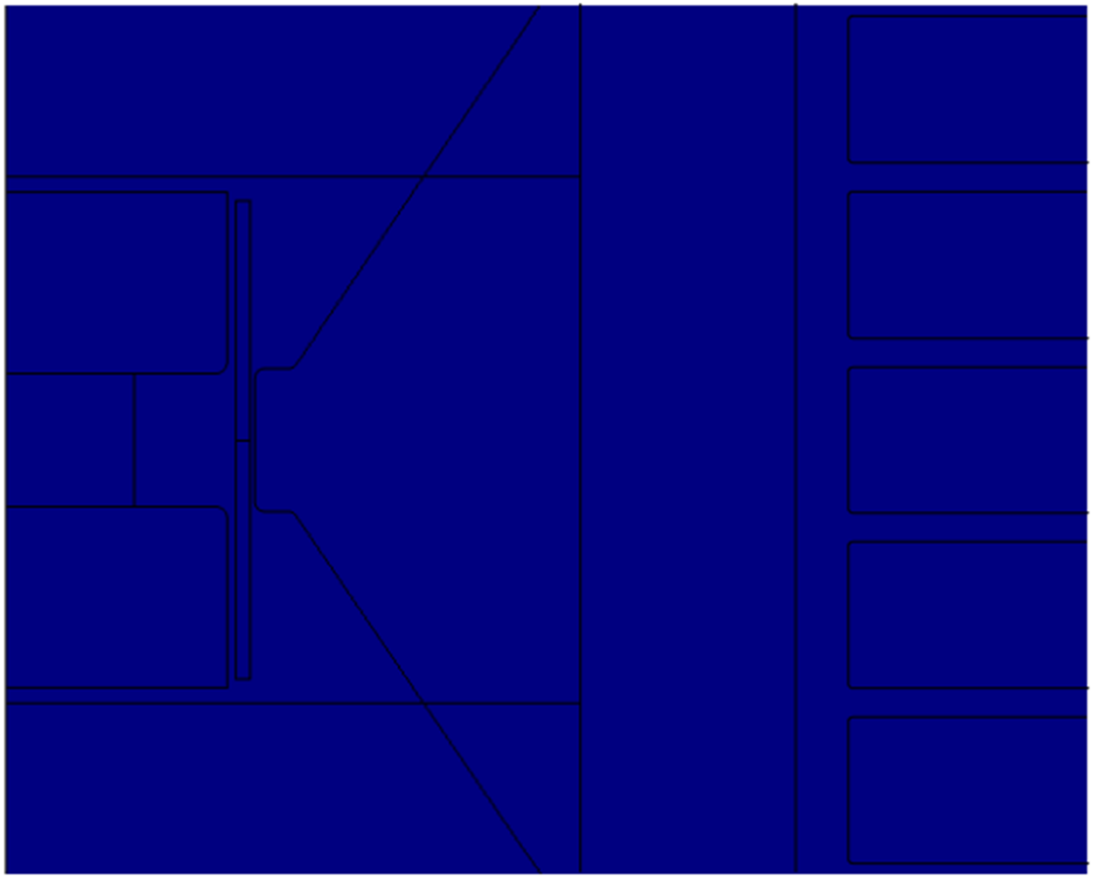
Multiphysics model: Magnetic Fields



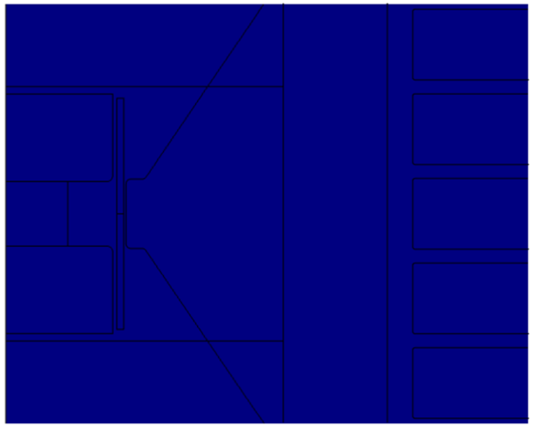
Flux density



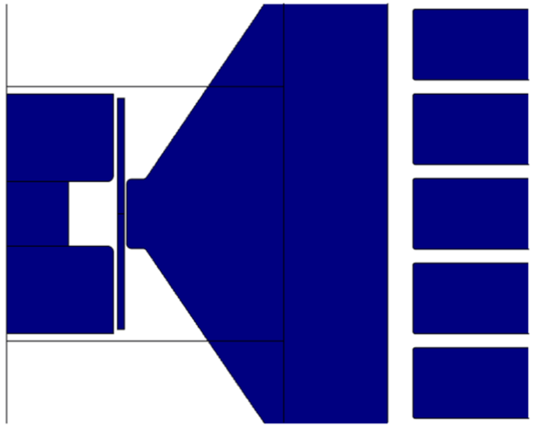
Current density



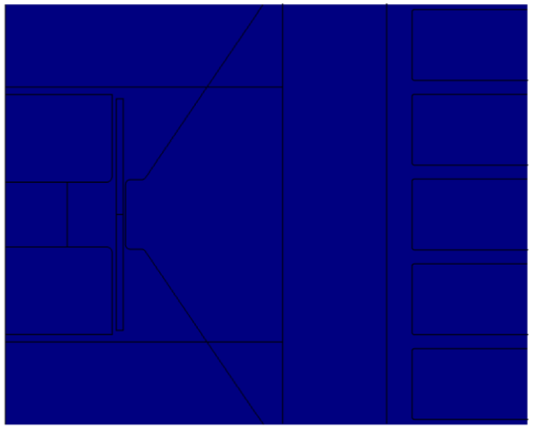
B



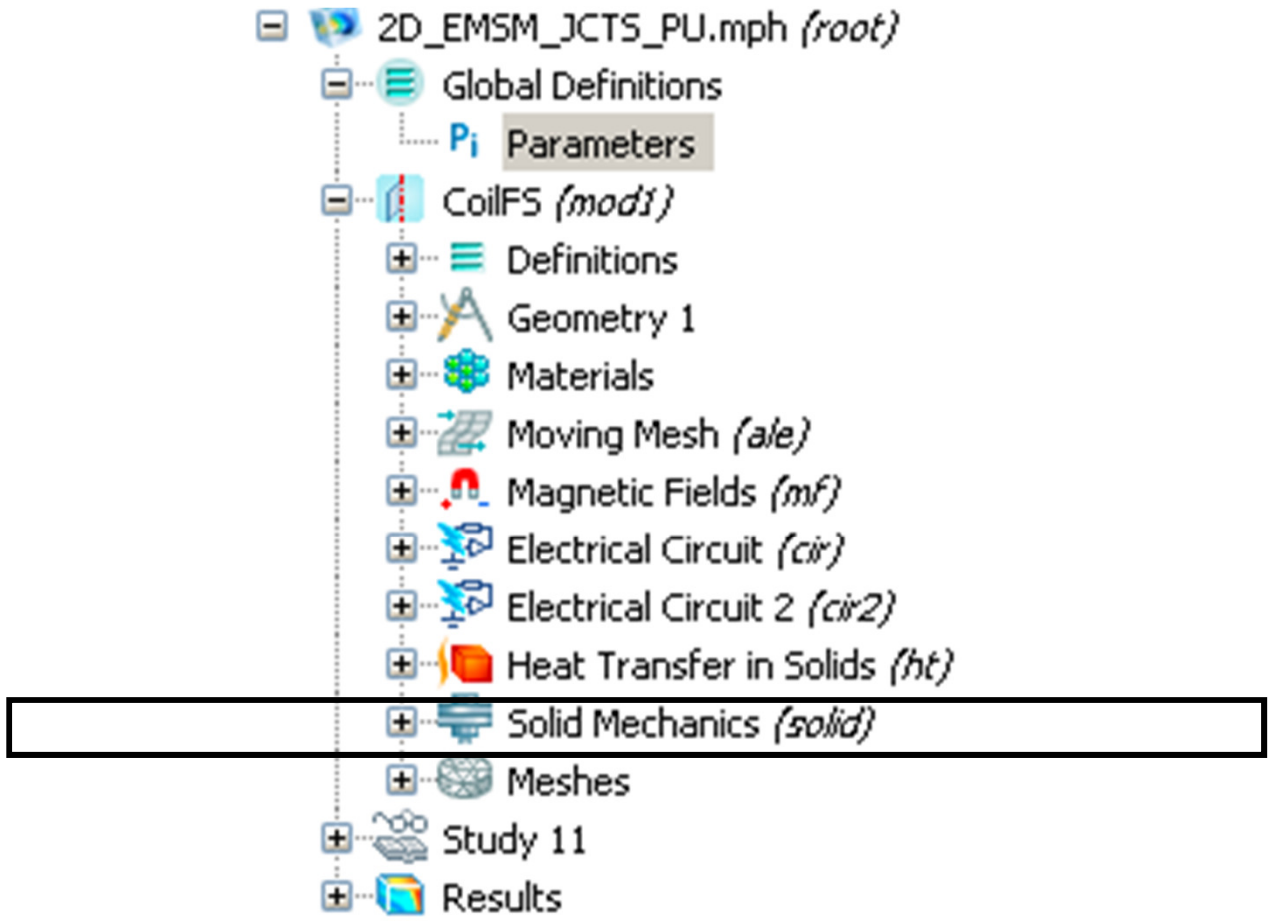
F



J



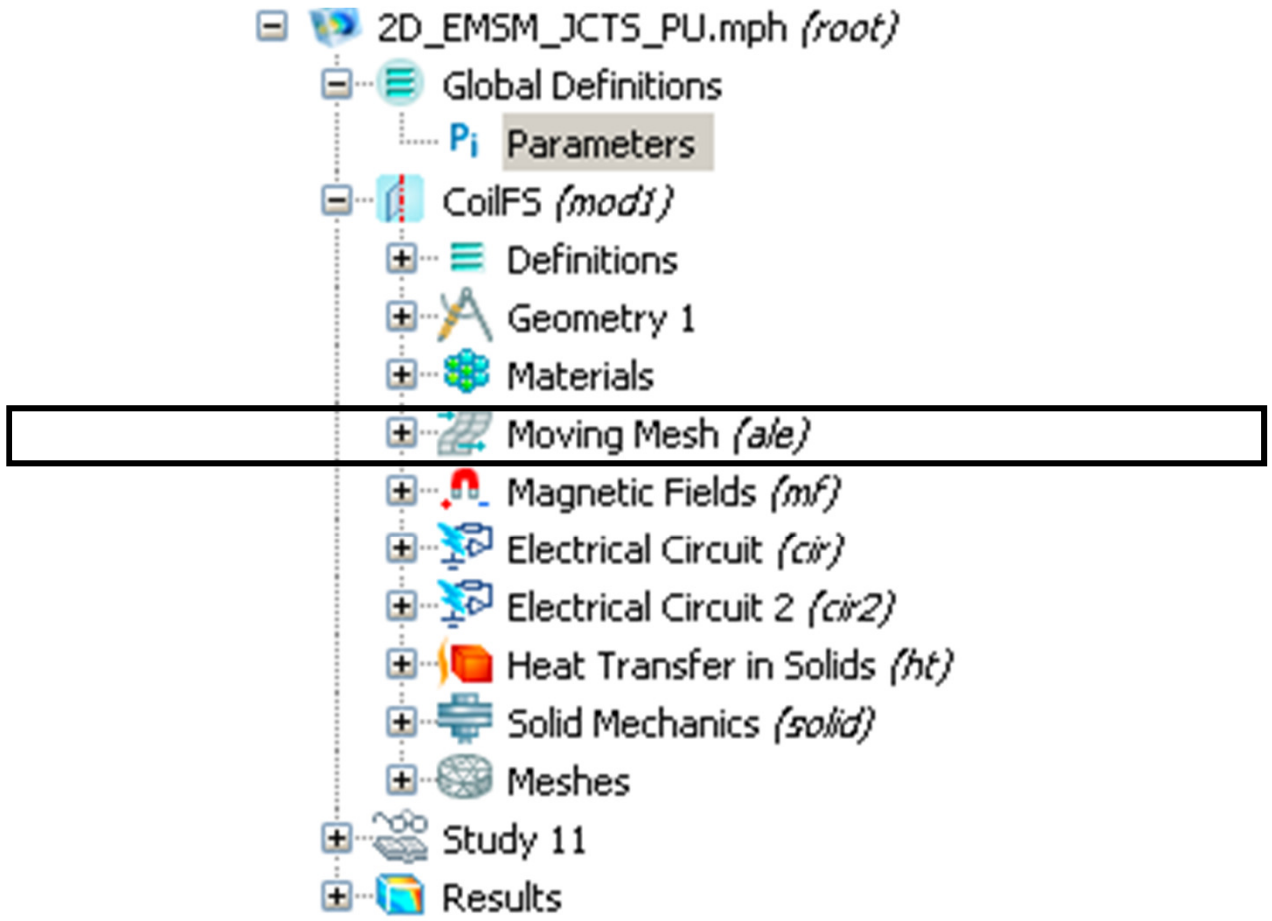
Multiphysics model: Solid Mechanics



Solid Mechanics

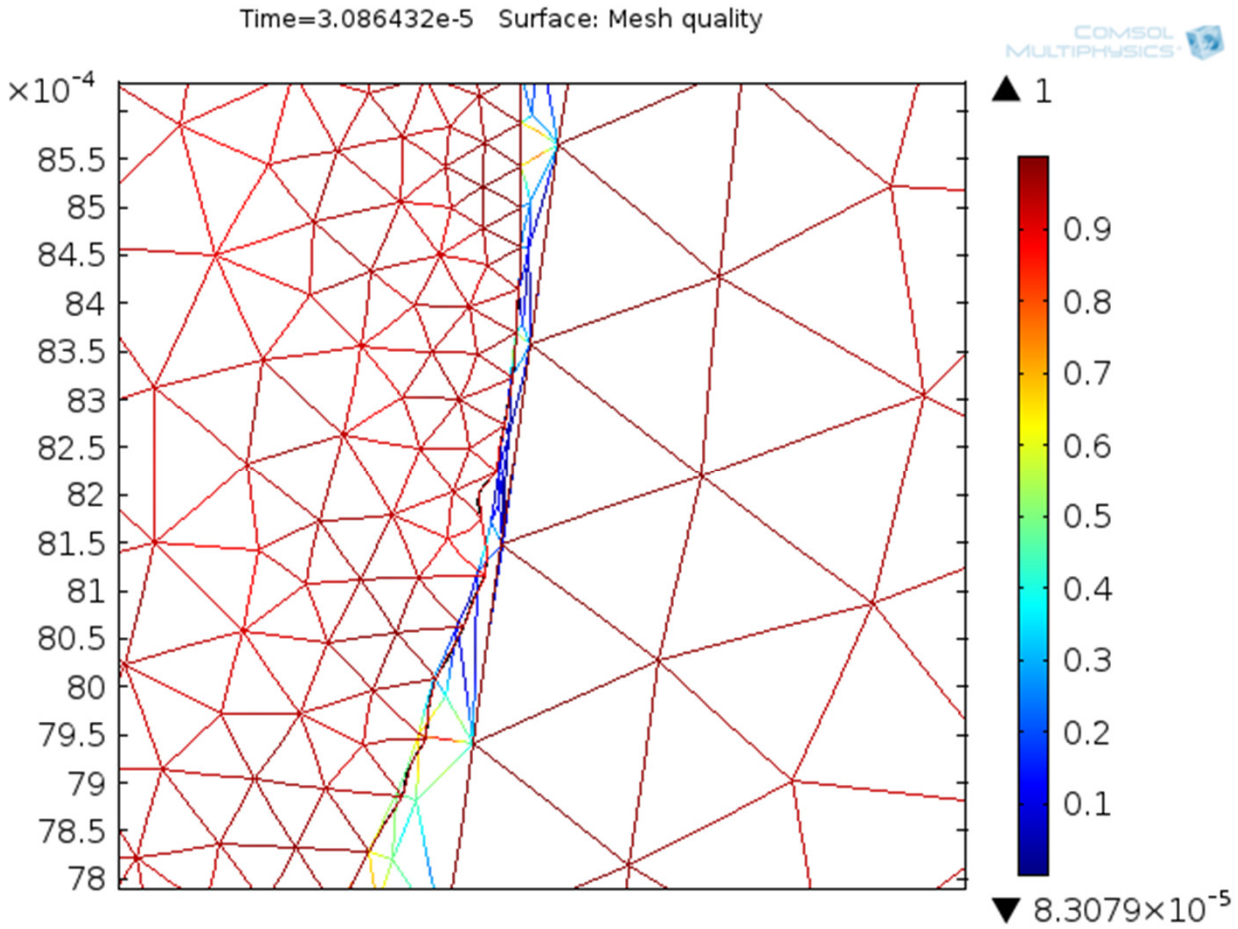
- **Input**
  - ✓ Lorentz forces as body load
- **Results**
  - ✓ Displacements / deformations
  - ✓ (Plastic) strains
  - ✓ Stresses
- **Utility**
  - ✓ Predicts final shape
  - ✓ Useful for tool design / durability prediction

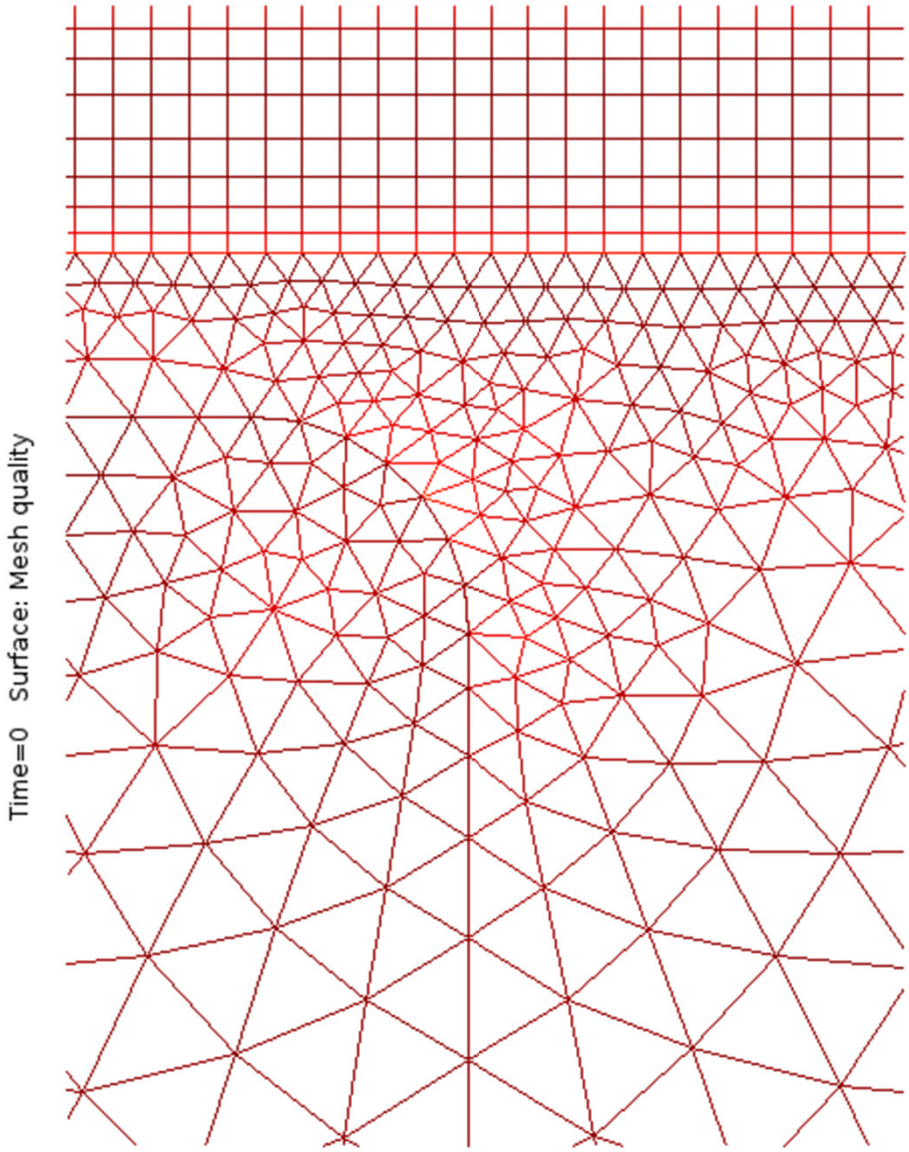
Multiphysics model: Moving Mesh

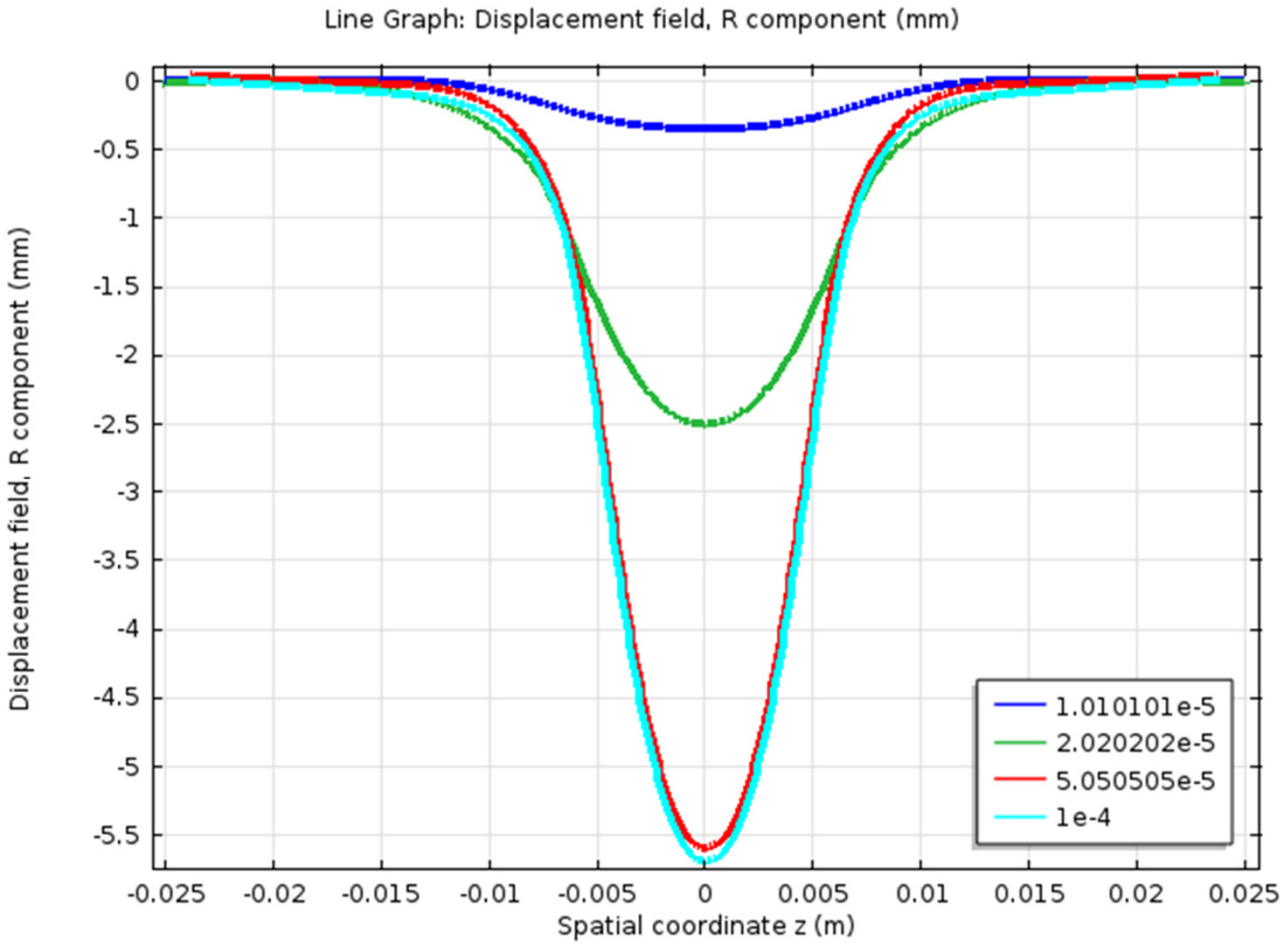


- **Large deformations :**
  - ✓ meshes highly deformed
  - ✓ Convergence problems
- **Solution**
  - ✓ Moving meshes
  - ✓ Automatic remeshing when quality low

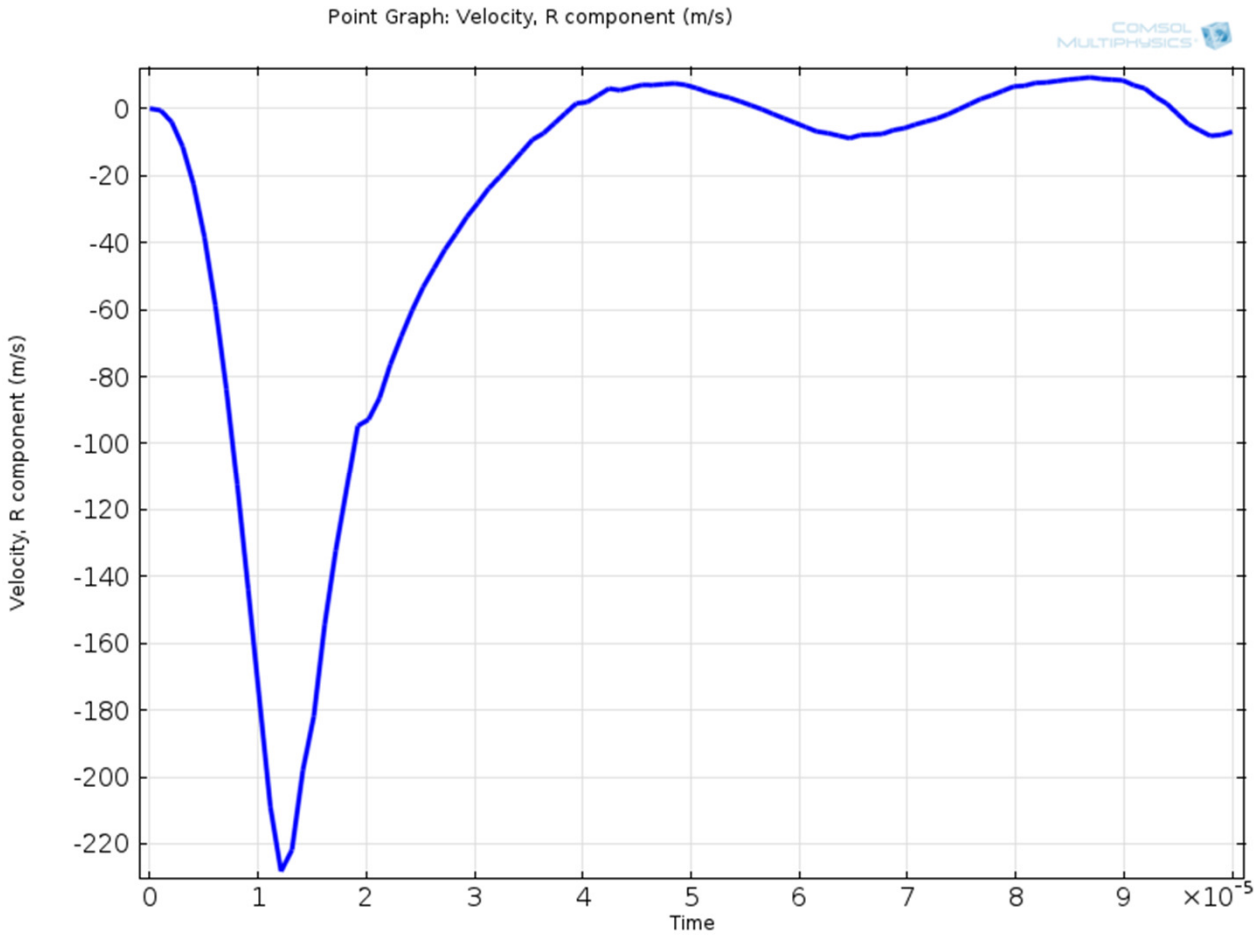
Contact offset necessary



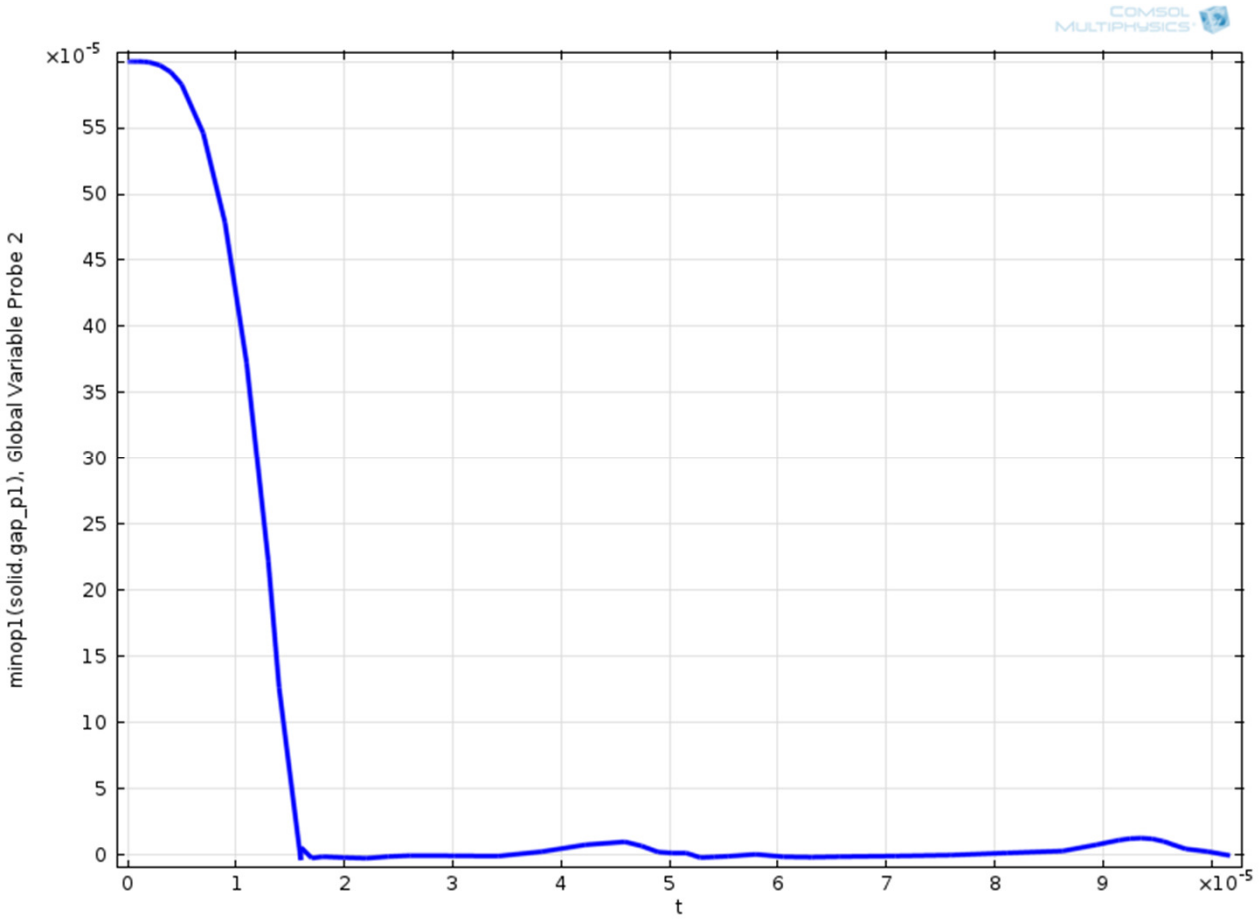




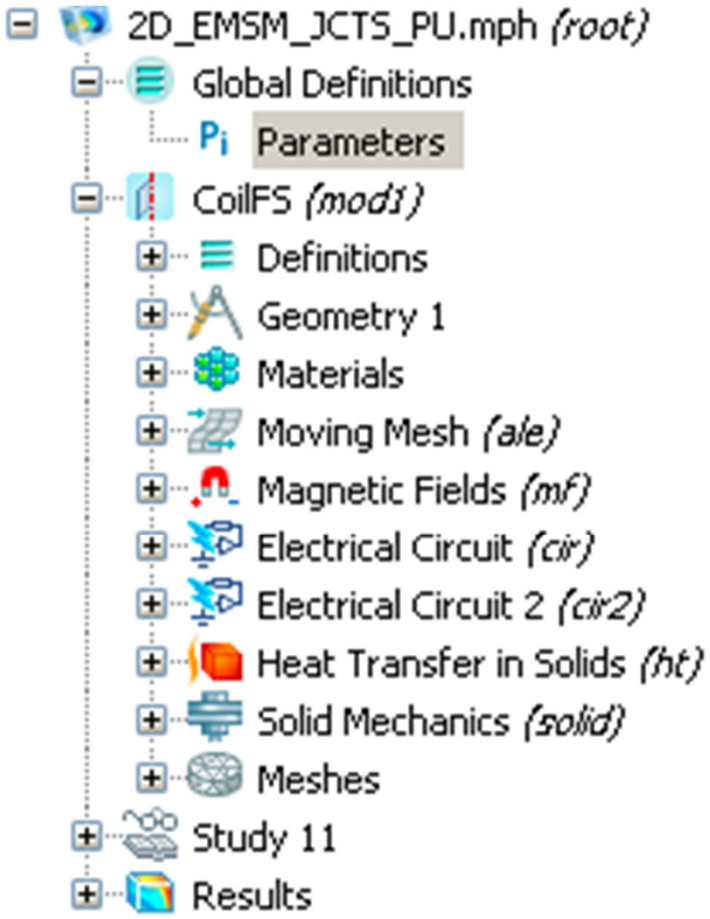
Velocity tube center



Gap tube – mandrel



Multiphysics model



To conclude

- **The PulsCrimp models extend the MagPuls models by**
  - ✓ Allowing larger deformations
  - ✓ Fully integrate electric circuit and field shaper
  - ✓ Being fully parametrized

Questions ?