FCC WEEK 2018
AMSTERDAM, The Netherlands
09 - 13 APRIL

STEAM

INFN
GENOVA
MILANO

cea
SACLAY

Analysis of mechanical stress during quench

M. Prioli

with contributions from: M. Maciejewski, T. Salmi, B. Auchmann, A. Verweij, A. Stenvall, B. Caiffi, S. Farinon, V. Marinozzi, M. Sorbi, M. Durante, C. Lorin, E. Rochepault, M. Segreti

Acknowledgments: P. Bayrasy, K. Wolf, *Fraunhofer SCAI*

The European Circular Energy-Frontier Collider Study (EuroCirCol) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 654305. The information herein only reflects the views of its authors and the European Commission is not responsible for any use that may be made of the information.

EuroCirCol

Design phases for the FCC dipole magnets

Electromagnetic design

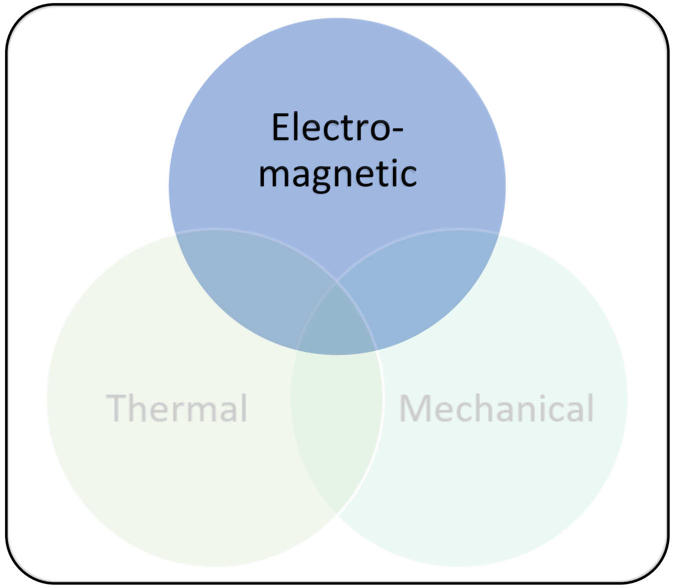
In "*EuroCirCol 16 T designs for the FCC CDR*"

B. Caiffi, E. Rochepault, F. Toral

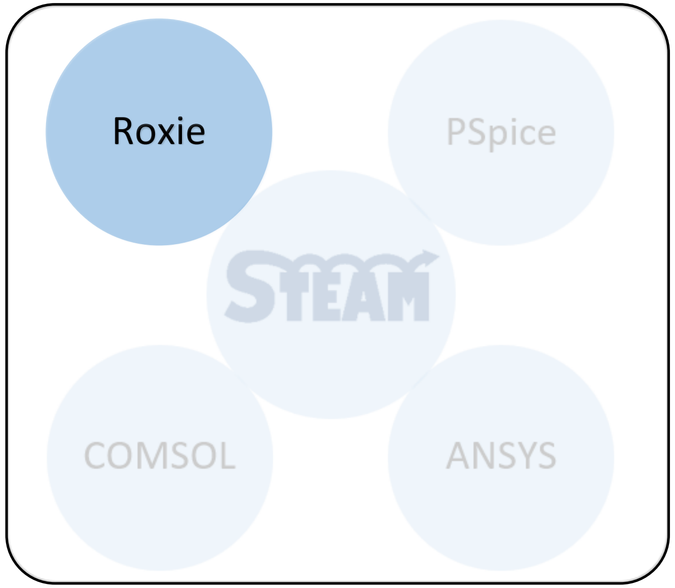
Tuesday afternoon

Final Magnet Design

Physical Domains



Simulation Tools



Design phases for the FCC dipole magnets

Electromagnetic design

In “*EuroCirCol 16 T designs for the FCC CDR*”

B. Caiffi, E. Rochepault, F. Toral

Tuesday afternoon

Mechanical design

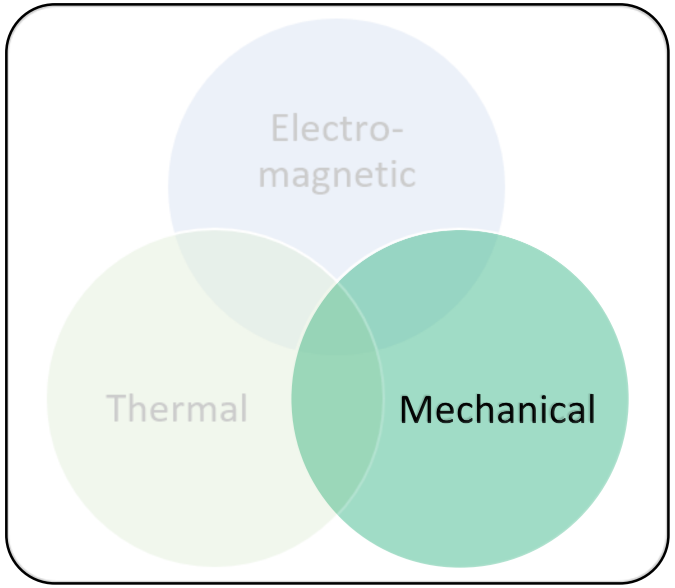
In “*EuroCirCol 16 T designs for the FCC CDR*”

B. Caiffi, E. Rochepault, F. Toral

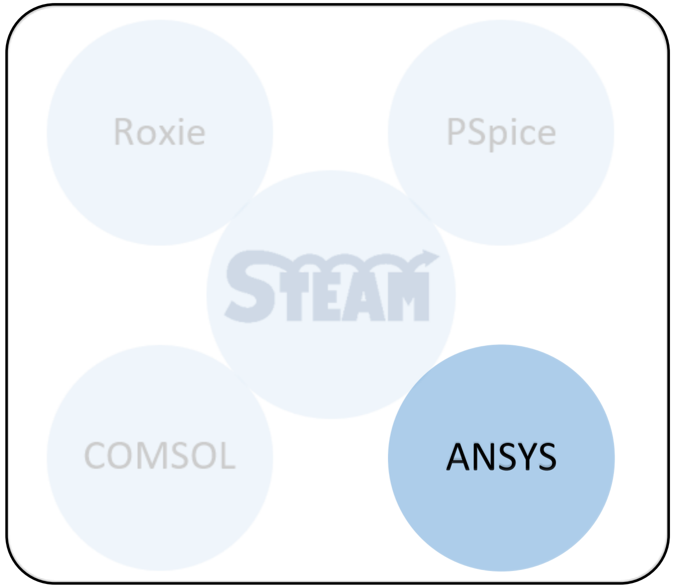
Tuesday afternoon

Final Magnet Design

Physical Domains



Simulation Tools



Design phases for the FCC dipole magnets

Electromagnetic design

In *“EuroCirCol 16 T designs for the FCC CDR”*
B. Caiffi, E. Rochepault, F. Toral
Tuesday afternoon

Mechanical design

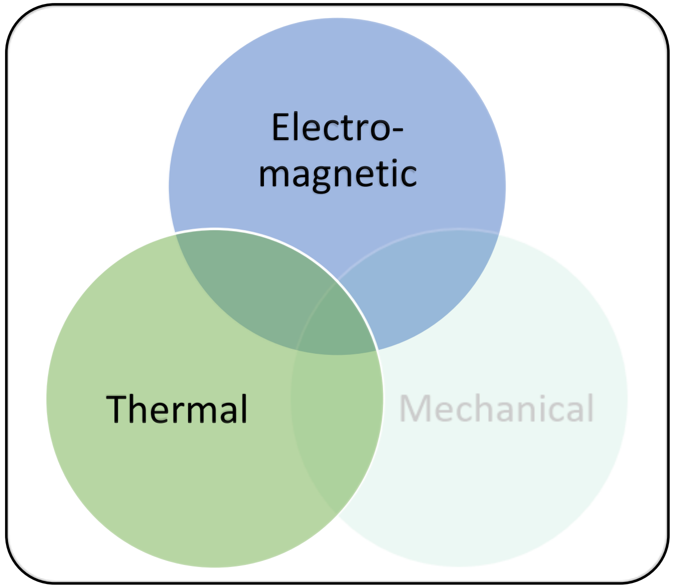
In *“EuroCirCol 16 T designs for the FCC CDR”*
B. Caiffi, E. Rochepault, F. Toral
Tuesday afternoon

Quench protection design (CLIQ)

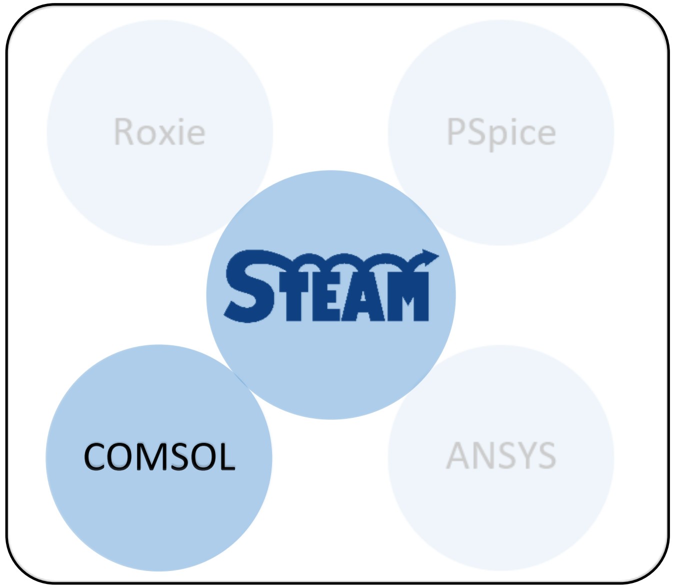
In *“EuroCirCol 16 T dipole magnet quench protection”*
T. Salmi
This session

Final Magnet Design

Physical Domains



Simulation Tools



Design phases for the FCC dipole magnets

Electromagnetic design

In *"EuroCirCol 16 T designs for the FCC CDR"*

B. Caiffi, E. Rochepault, F. Toral

Tuesday afternoon

Mechanical design

In *"EuroCirCol 16 T designs for the FCC CDR"*

B. Caiffi, E. Rochepault, F. Toral

Tuesday afternoon

Quench protection design (CLIQ)

In *"EuroCirCol 16 T dipole magnet quench protection"*

T. Salmi

This session

Circuit design

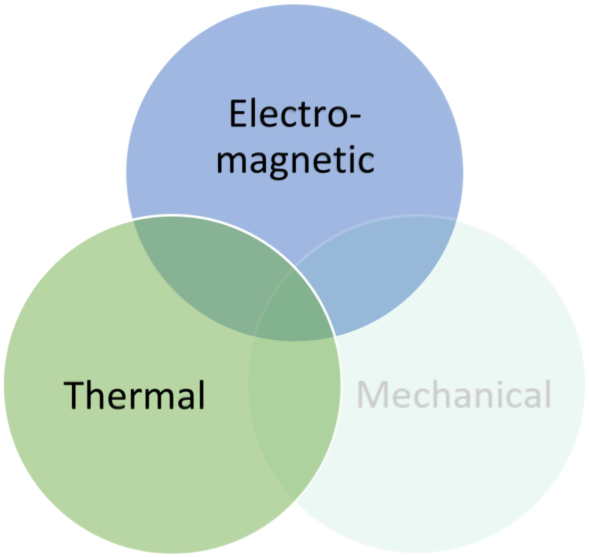
In *"Circuit layout and protection"*

M. Prioli

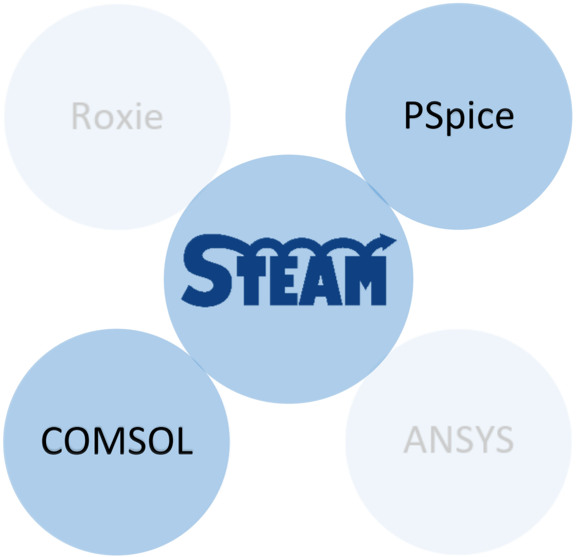
Thursday afternoon

Final Magnet Design

Physical Domains



Simulation Tools



Design phases for the FCC dipole magnets

Electromagnetic design
In *"EuroCirCol 16 T designs for the FCC CDR"*
B. Caiffi, E. Rochepault, F. Toral
Tuesday afternoon

Mechanical design
In *"EuroCirCol 16 T designs for the FCC CDR"*
B. Caiffi, E. Rochepault, F. Toral
Tuesday afternoon

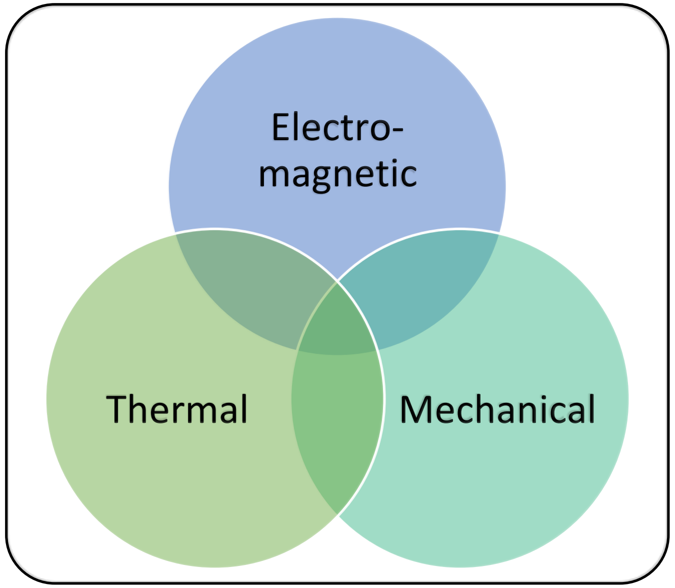
Quench protection design (CLIQ)
In *"EuroCirCol 16 T dipole magnet quench protection"*
T. Salmi
This session

Circuit design
In *"Circuit layout and protection"*
M. Prioli
Thursday afternoon

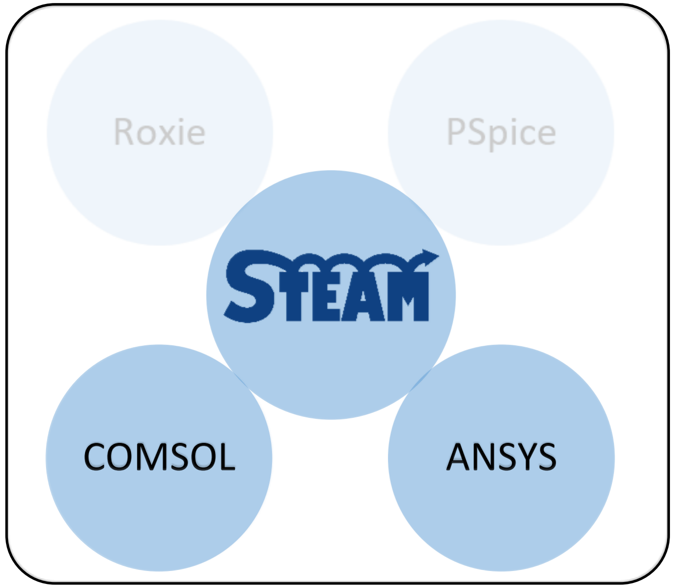
Quench mechanics
This presentation!

Final Magnet Design

Physical Domains



Simulation Tools

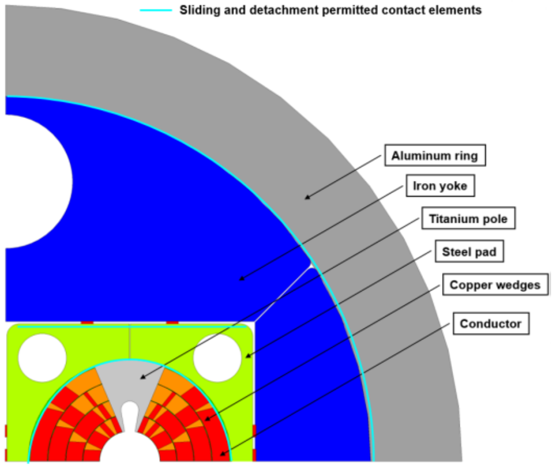


Outline

- Mesh-based interpolation technique
- EuroCirCol 16 T Cos-theta magnet
  - Crosscheck
  - Results
  - Comments
- EuroCirCol 16 T Block-coil magnet
  - Crosscheck
  - Results
  - Comments
- Conclusion

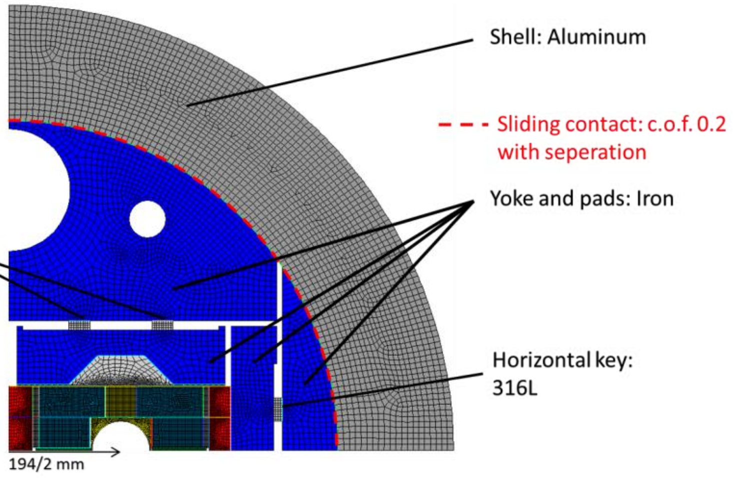
INFN

v22b_38_v1



cea

v2ari194



Outline

- Mesh-based interpolation technique
- EuroCirCol 16 T Cos-theta magnet
    - Crosscheck
    - Results
    - Comments
- EuroCirCol 16 T Block-coil magnet
    - Crosscheck
    - Results
    - Comments
- Conclusion

v22b_38_v1

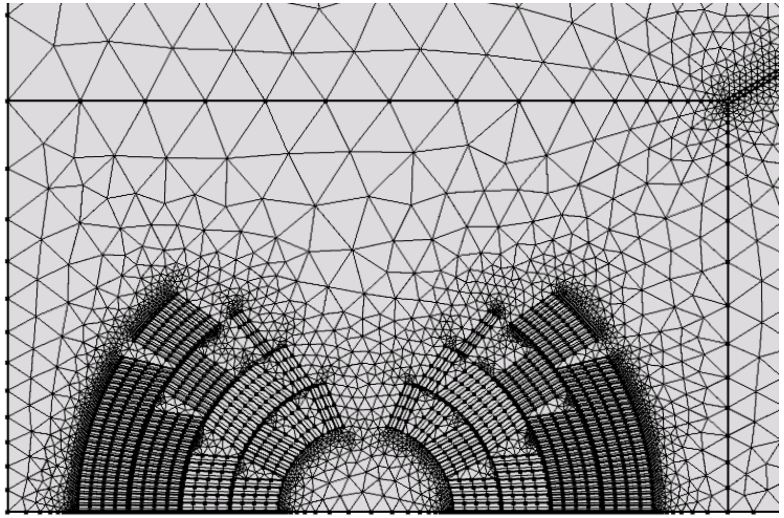
v2ari194

Coupling strategy [1]

FE models with different mesh (physics driven) can be coupled via mesh based interpolation

CLIQ quench simulation

COMSOL



Coupling Environment

MpCCI

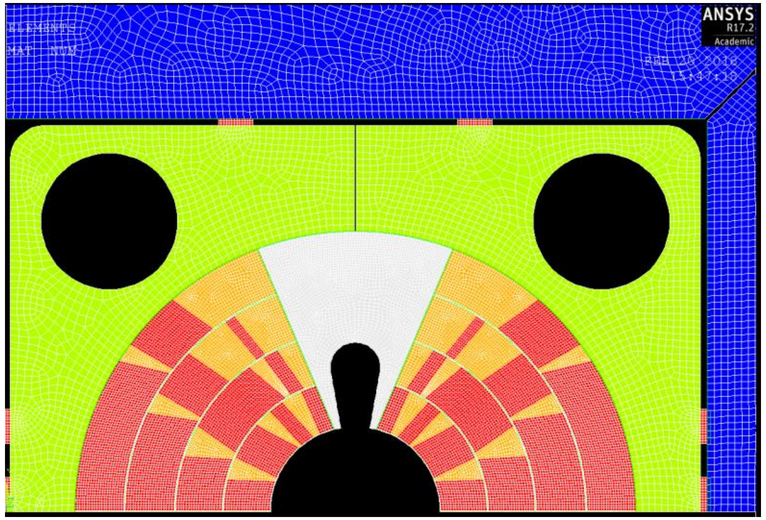
T → $\hat{T}$

$\vec{F}_L$ → $\widehat{\vec{F}_L}$

Mesh-based interpolation

Mechanical simulation

ANSYS



CERN

Fraunhofer SCAI

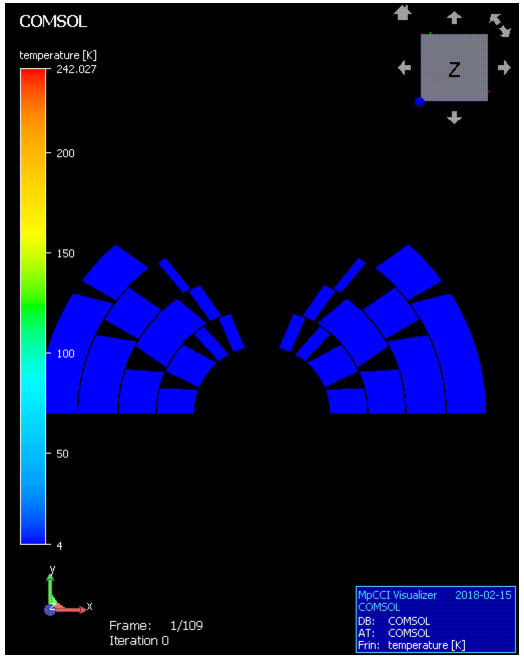
INFN

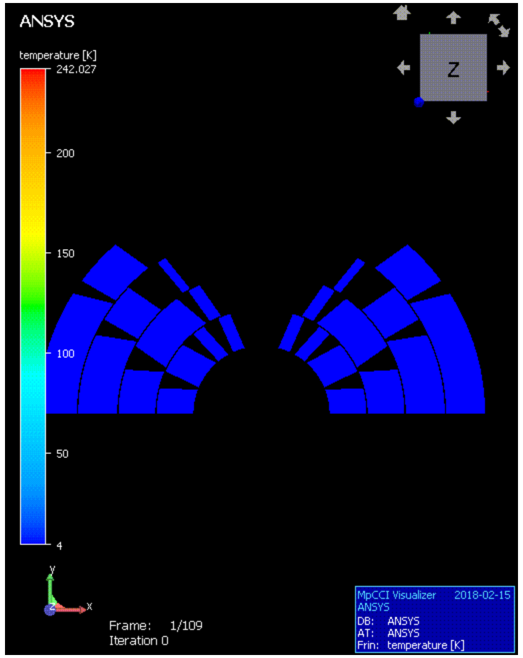
[1] M. Maciejewski et al., "Coupling of Magnetothermal and Mechanical Superconducting Magnet Models by Means of Mesh-Based Interpolation," in *IEEE Transactions on Applied Superconductivity*, vol. 28, no. 3, pp. 1-5, April 2018.

Data transfer preview in MpCCI GUI

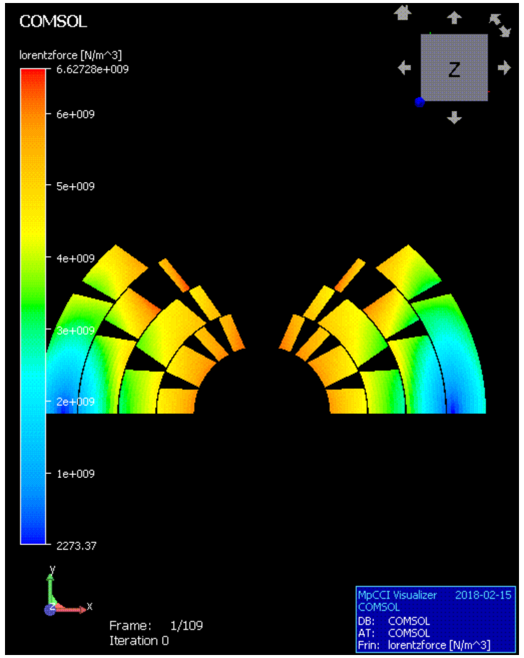
$t = 0$

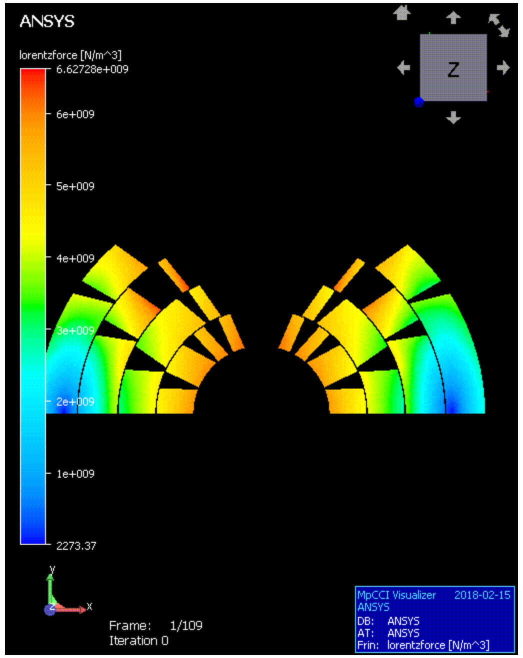
Temperature [K]





Lorentz force [Pa]



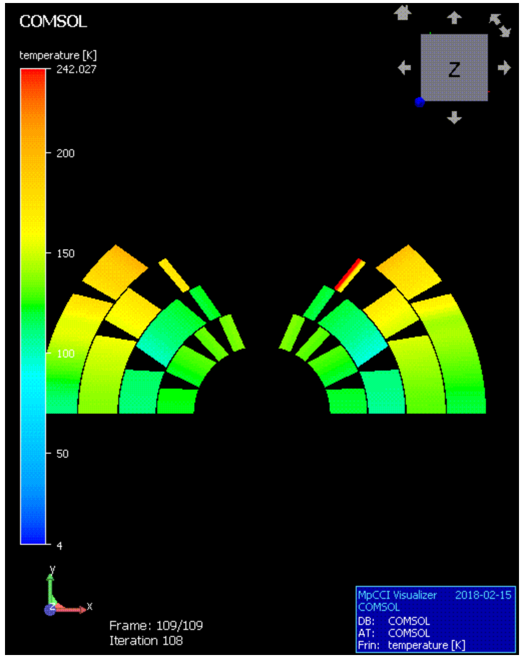


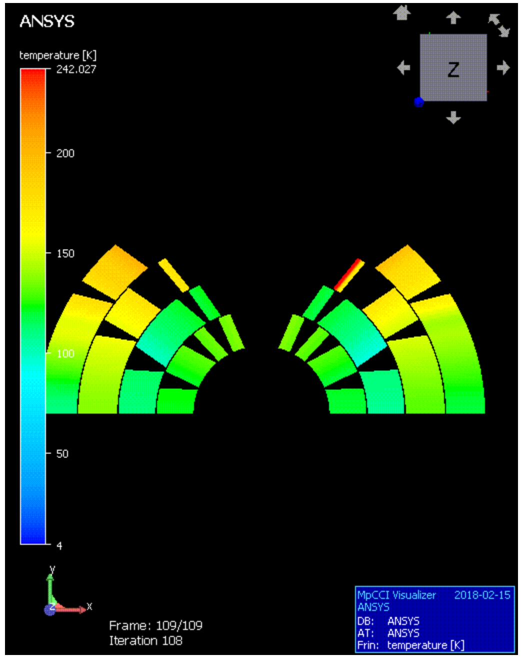
Data transfer preview in MpCCI GUI

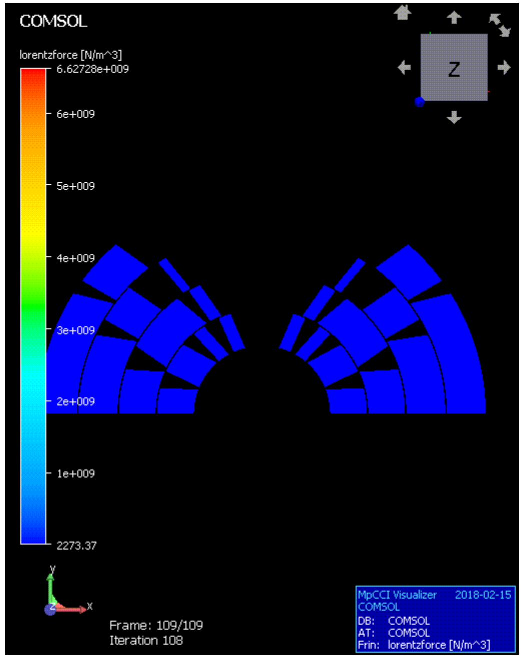
Temperature [K]

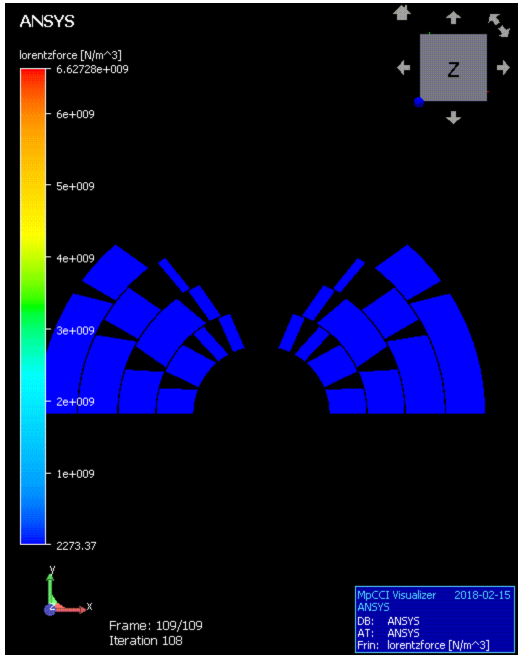
$t = t_{end}$

Lorentz force [Pa]





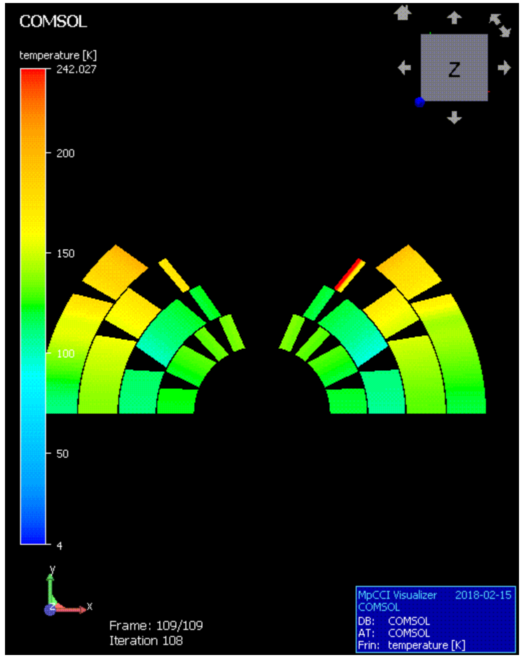


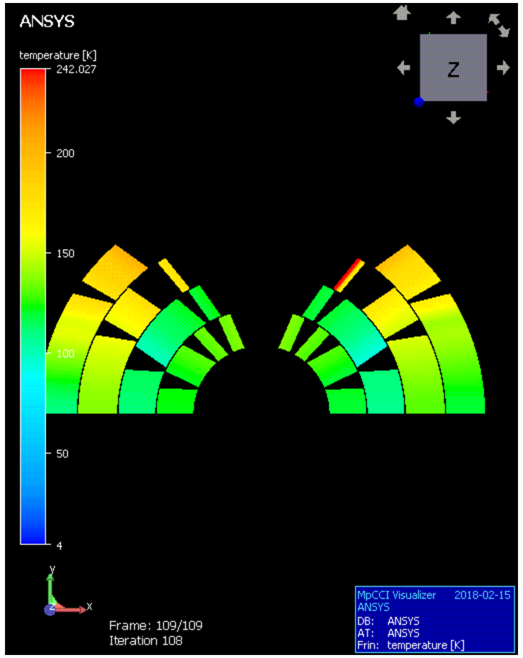


Data transfer preview in MpCCI GUI

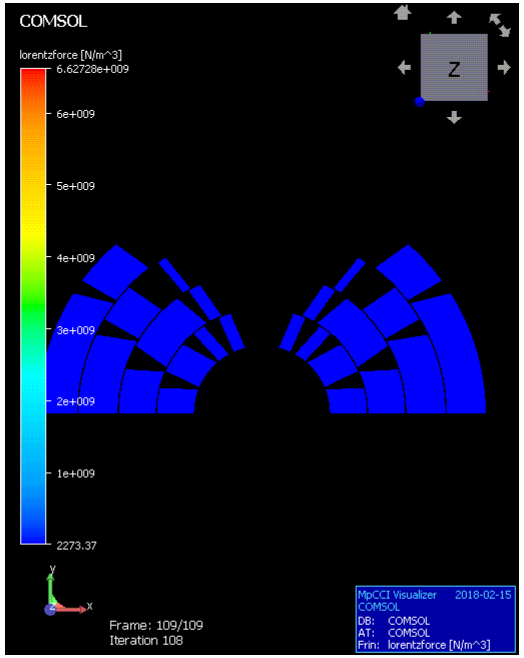
$t = t_{end}$

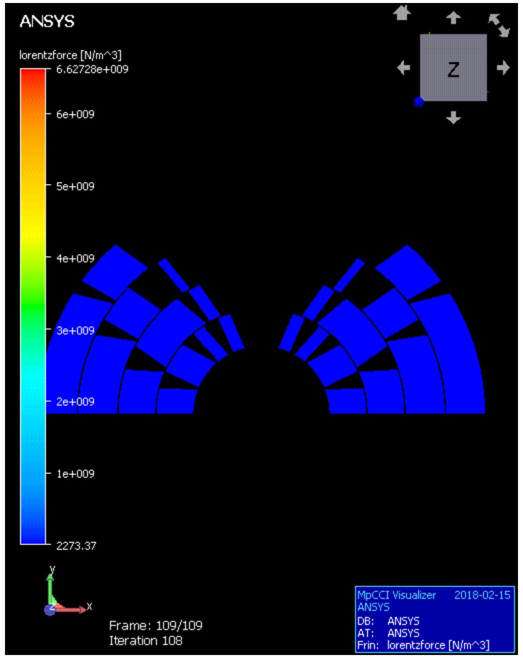
Temperature [K]





Lorentz force [Pa]





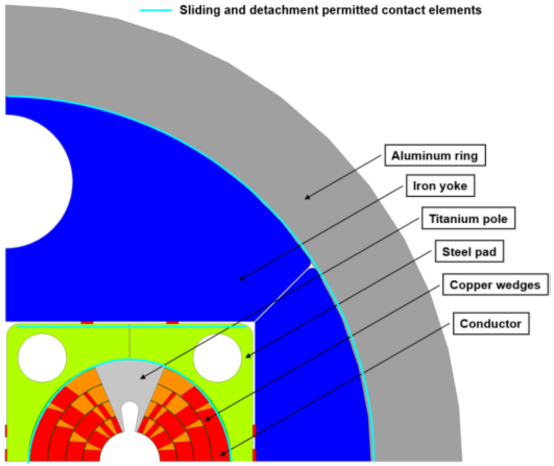
Temperature differences are increasing while Lorentz force is decreasing during discharge

→ Non trivial prediction of the moment of peak mechanical stress

Outline

- Mesh-based interpolation technique
- EuroCirCol 16 T Cos-theta magnet
    - Crosscheck
    - Results
    - Comments
- EuroCirCol 16 T Block-coil magnet
    - Crosscheck
    - Results
    - Comments
- Conclusion

v22b_38_v1

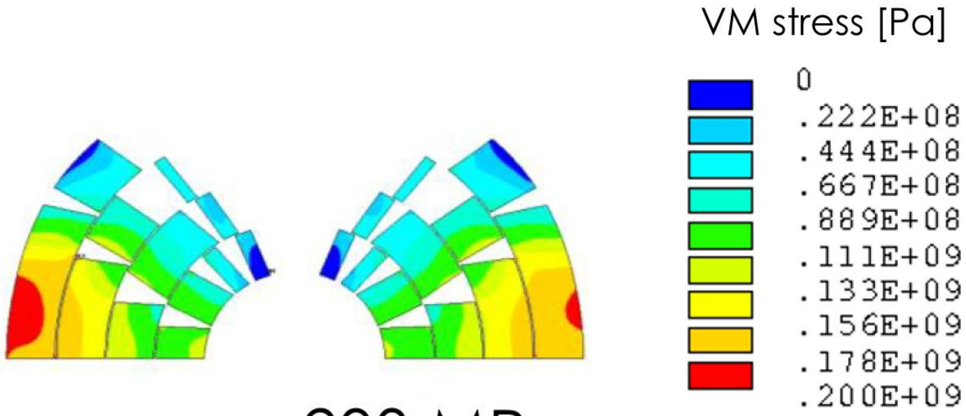


v2ari194

Crosscheck at nominal current (t = 0)

Reference simulation from B. Caiffi:

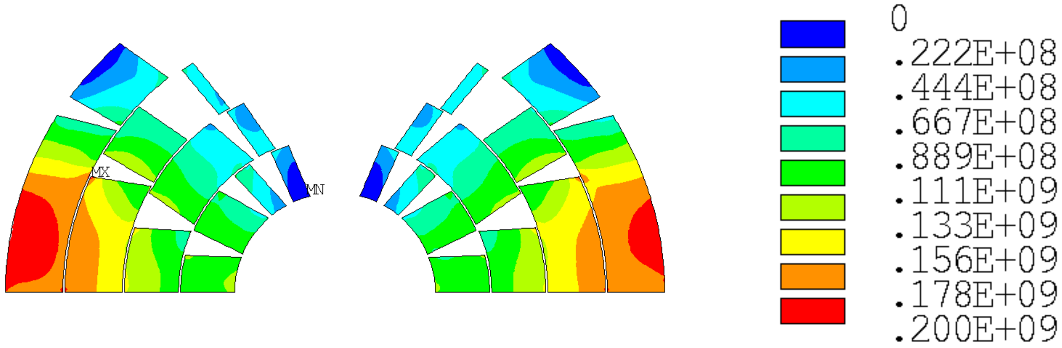
Lorentz force from ROXIE → Mechanics in ANSYS



$\sigma_{VM,max} = 203$ MPa

Simulation to be validated:

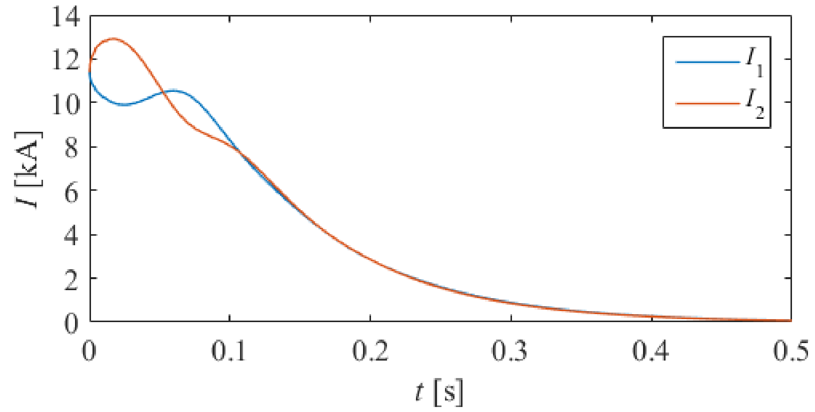
Lorentz force from COMSOL → Mechanics in ANSYS

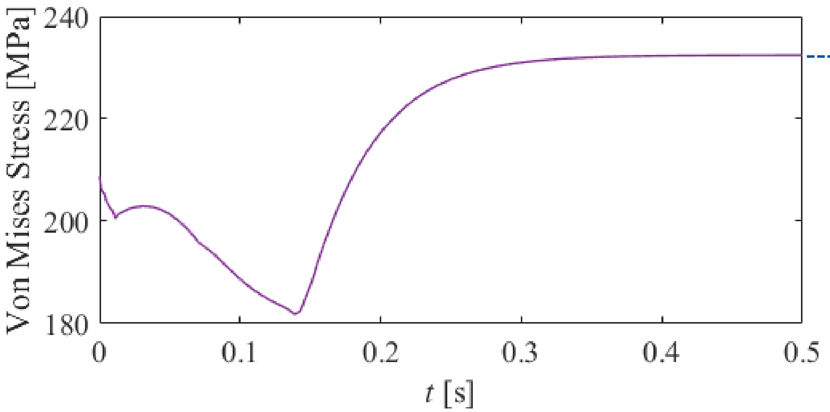


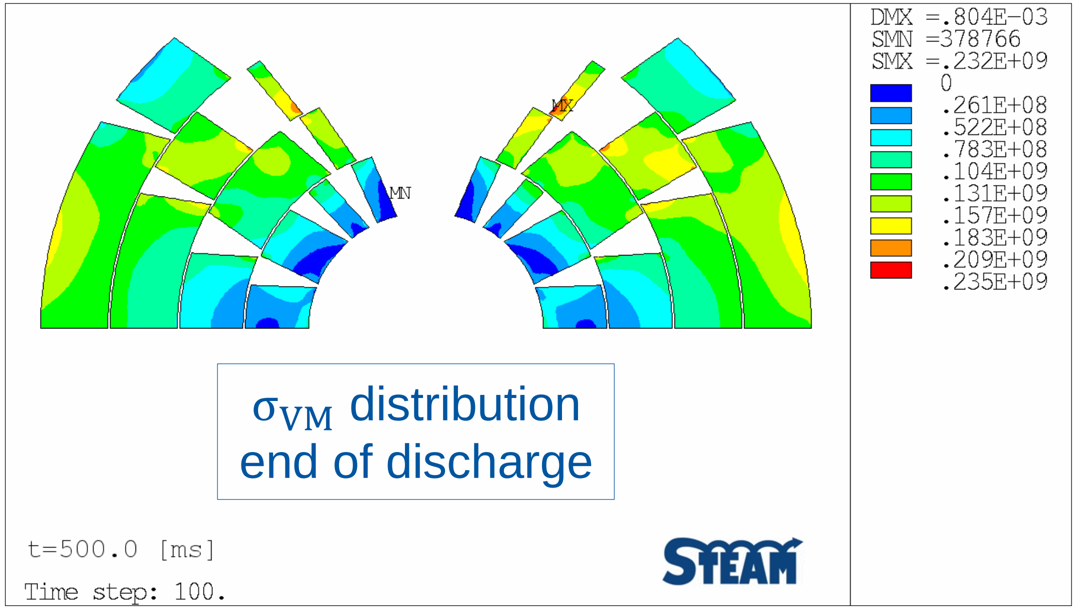
$\sigma_{VM,max} = 208$ MPa

✓ Very similar stress distribution for the two approaches!

Case 1: CLIQ is triggered without an original quench



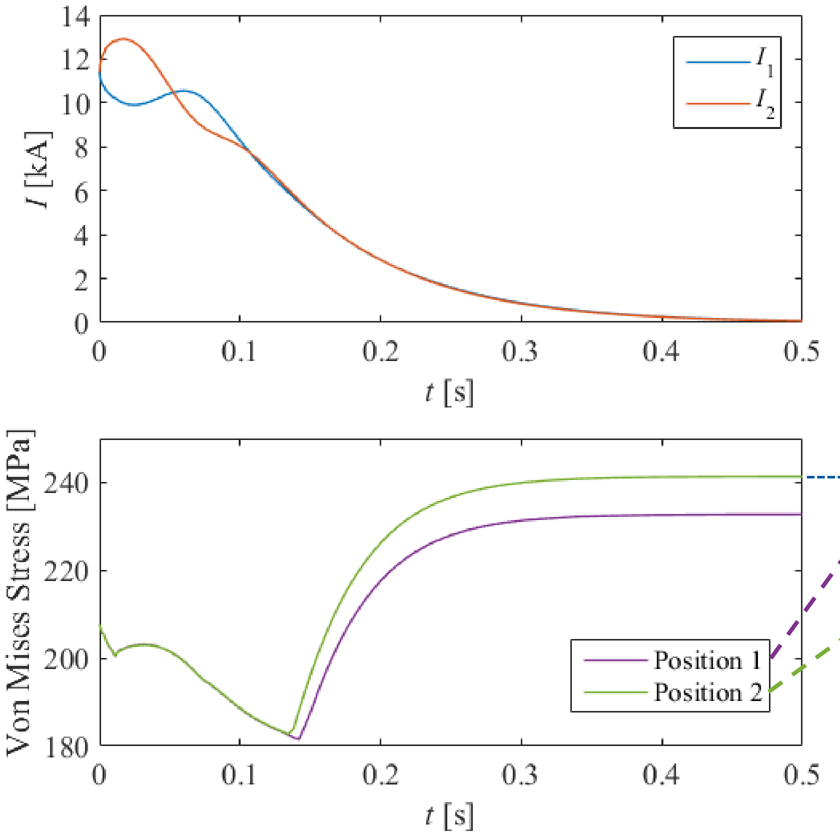


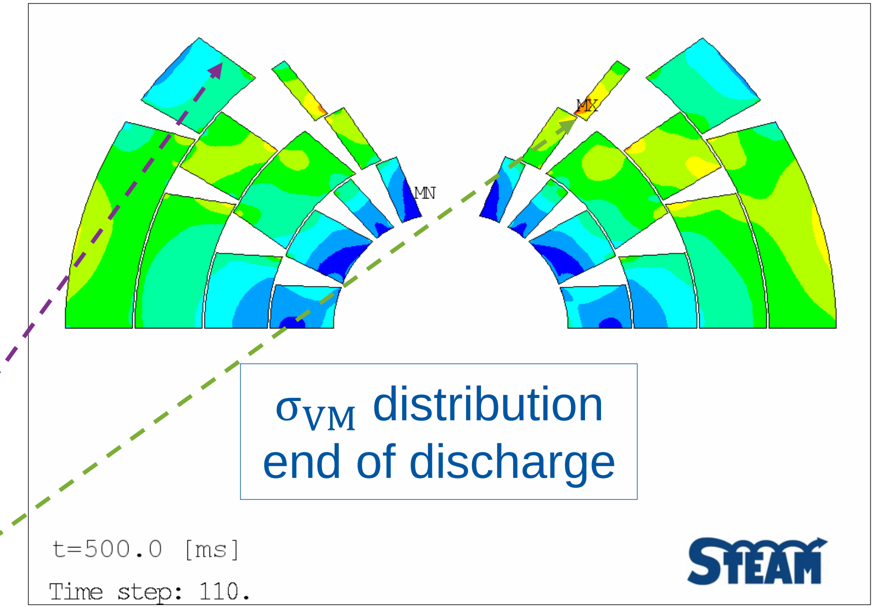


$\sigma_{VM,max} = 232$ MPa at the end of the discharge

Case 2: CLIQ is triggered in presence of a quench

- Maximum temperature calculated in adiabatic conditions
- The quenched turn is: 1 - with maximum temperature, 2 - with maximum stress





$\sigma_{VM,max} = 241$ MPa at the end of the discharge

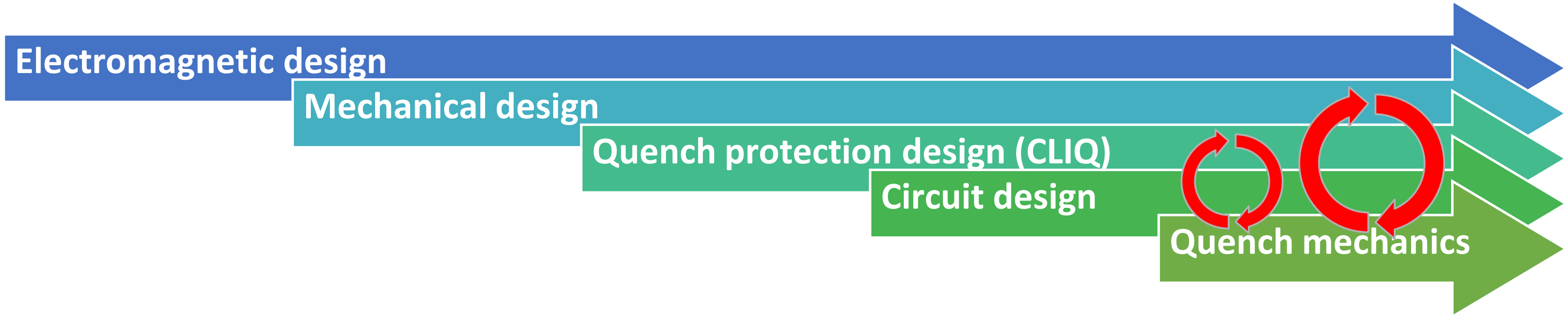
Comments

- Peak stress is at the end of current discharge
  - Maximum temperature differences
  - 208 MPa @ energization → 232 MPa after a quench

- The worst quench location is in the half-turn with maximum stress

  → 241 MPa after a quench in the peak stress location

➢ Recent result: mitigation strategies are being put in place
  - Optimization of mechanical design
  - Optimization of quench protection system

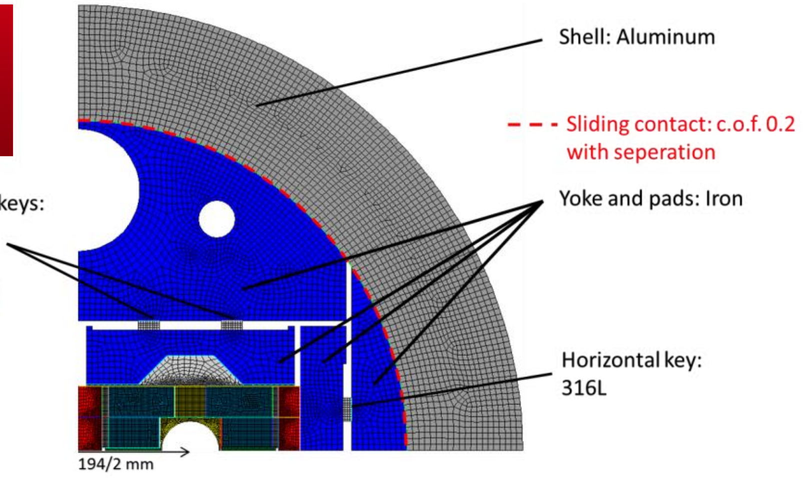


Outline

- Mesh-based interpolation technique
- EuroCirCol 16 T Cos-theta magnet
  - Crosscheck
  - Results
  - Comments
- **EuroCirCol 16 T Block-coil magnet**
  - **Crosscheck**
  - **Results**
  - **Comments**
- Conclusion

v22b_38_v1

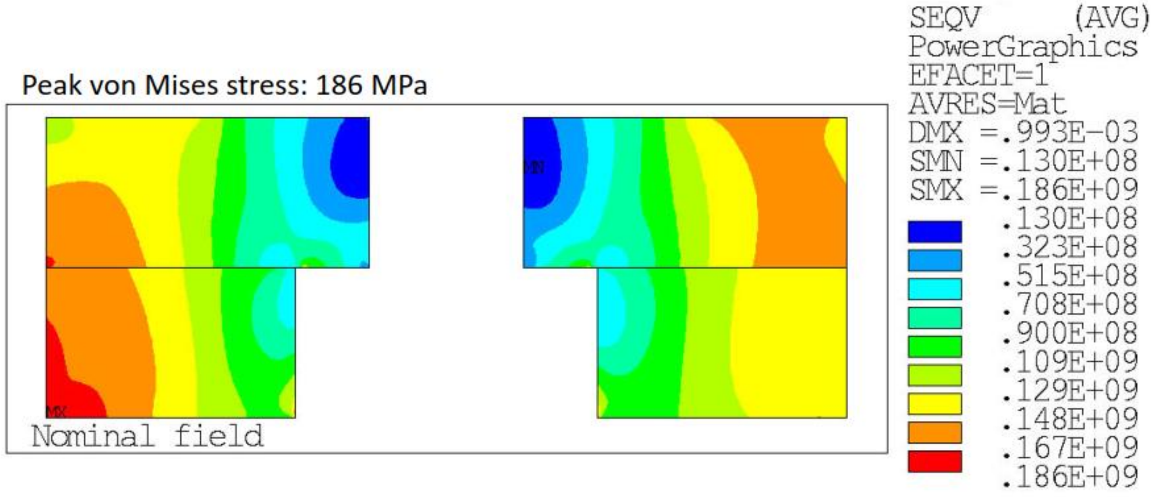
v2ari194



Crosscheck at nominal current (t = 0)

Reference simulation from C. Lorin:

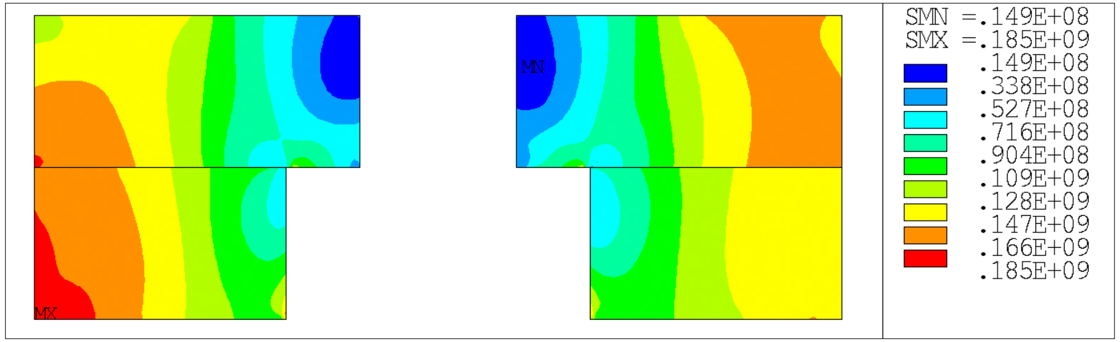
Lorentz force in ANSYS → Mechanics in ANSYS



Simulation to be validated:

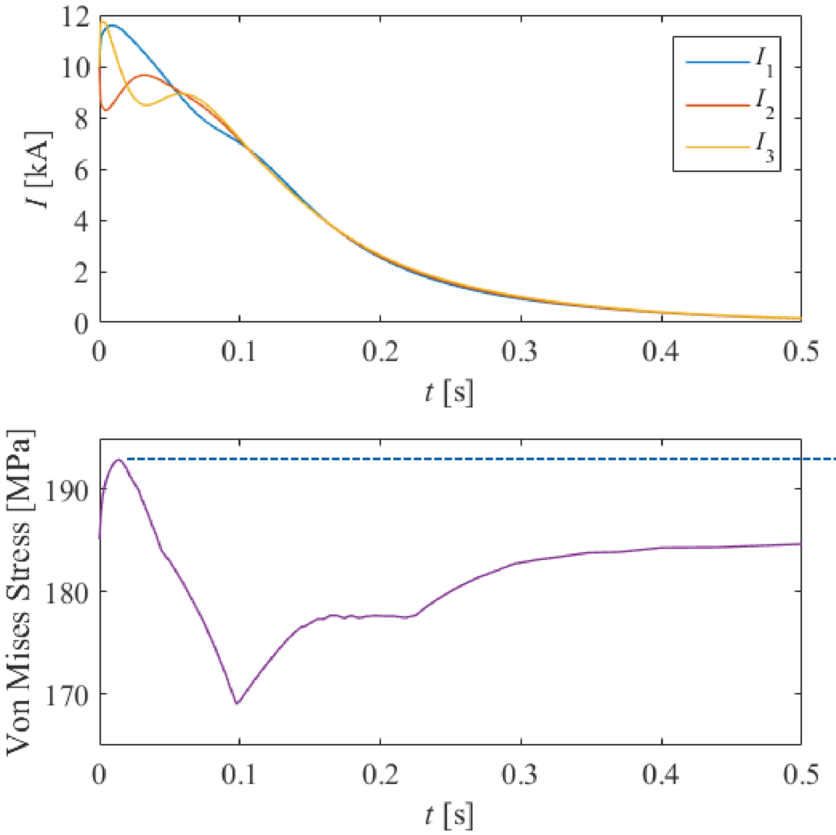
Lorentz force from COMSOL → Mechanics in ANSYS

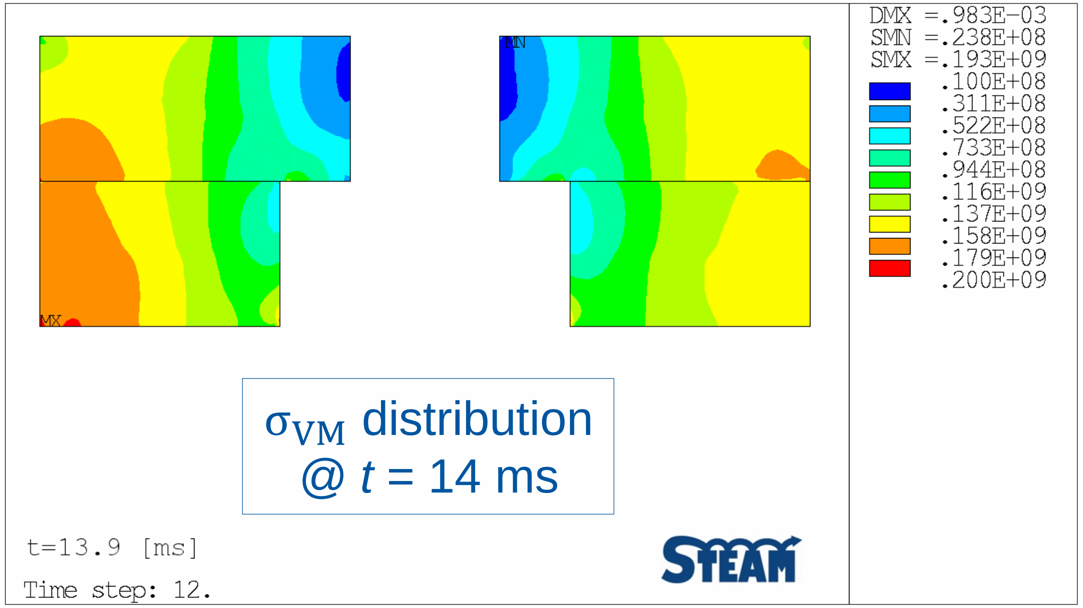
Peak Von Mises stress: 185 MPa



✓ Very similar stress distribution for the two approaches!

Case 1: CLIQ is triggered without an original quench

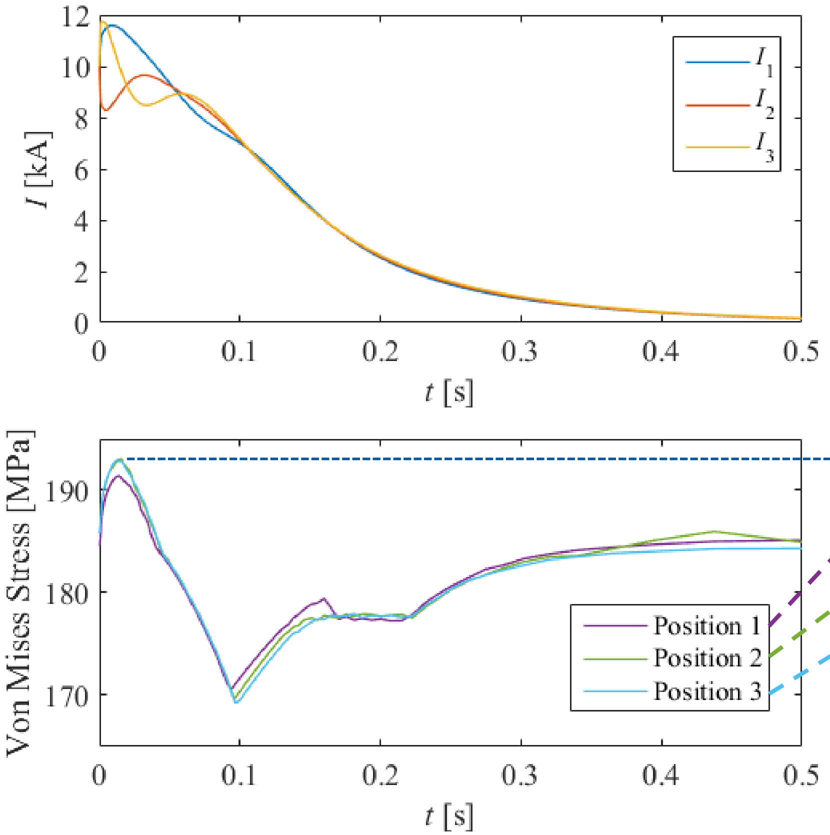


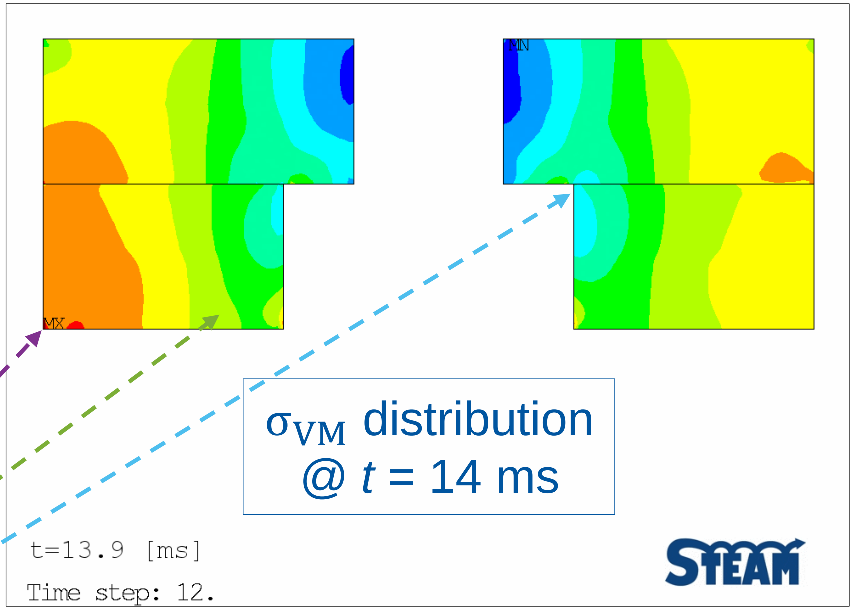


$\sigma_{VM,max}$ = 193 MPa at t = 14 ms

Case 2: CLIQ is triggered in presence of a quench

- Maximum temperature calculated in adiabatic conditions
- The quenched turn is: 1 and 3 - with maximum stress, 2 - with maximum temperature





$\sigma_{VM,max} = 193$ MPa at t = 14 ms

Comments

- Peak stress at *t* = 14 ms
  - Combination of Lorentz force introduced by CLIQ and temperature differences
  - 185 MPa @ energization → 193 MPa after a quench

- The quench location is not influencing the maximum stress

➢ No need to update mechanical design and quench protection system

Conclusion

The effect of the quench on the mechanical stress is different for cos-theta and block-coil magnets

- The peak stress during quench for cos-theta
  - Is significantly higher than at energization
  - Occurs at the end of the discharge ($t > 500$ ms)
- The peak stress during quench for block-coil
  - Is slightly higher than at energization
  - Occurs during the CLIQ discharge ($t = 14$ ms)

➢ For both magnets, quench increases the stress above the peak values foreseen during the mechanical design

➢ The full quench evolution needs to be considered in the mechanical stress analysis

➢ Mesh based interpolation allows using existing quench and mechanical models