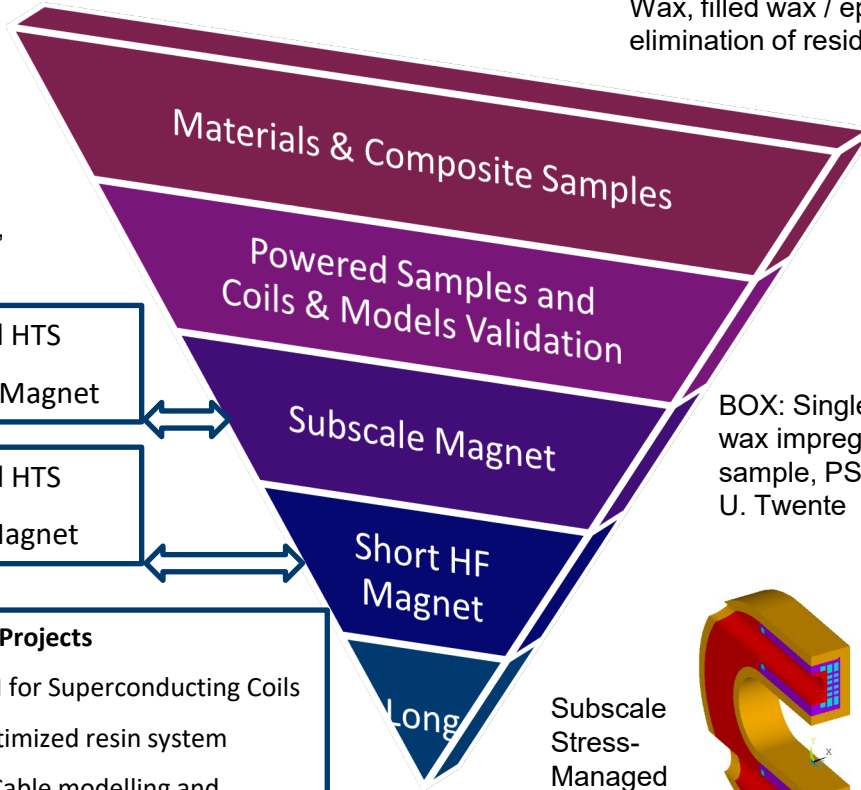


# LTS & Hybrid Roadmap Outlook

Wax, filled wax / epoxy process development, HT elimination of residues and sliding interfaces, A. Brem



D. Sotnikov,  
H. Garcia

Hybrid HTS  
Subscale Magnet

Hybrid HTS  
Short Magnet

### CHART Mag Projects

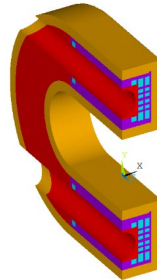
**MagAM:** AM for Superconducting Coils

**MagRes:** Optimized resin system

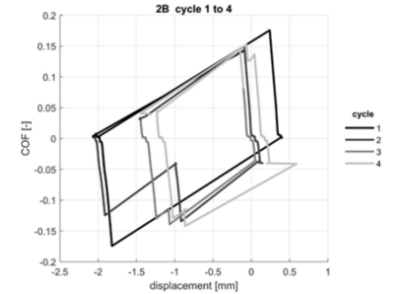
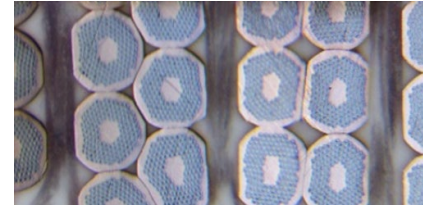
**MagComp:** Cable modelling and characterization

**MagNum:** Modelling & Optimization

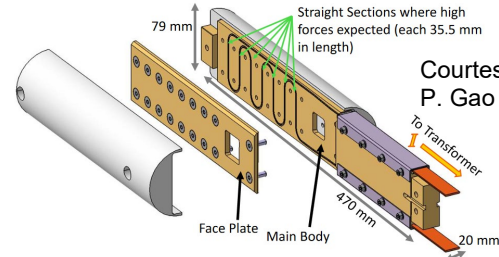
Subscale  
Stress-  
Managed  
Common-  
coils



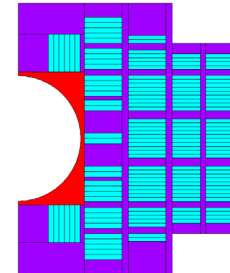
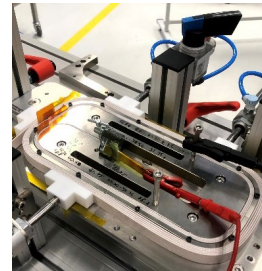
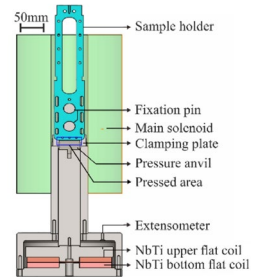
D. M. Araujo



BOX: Single-turn  
wax impregnated  
sample, PSI &  
U. Twente



Courtesy  
P. Gao



High-Field  
Stress-managed  
common coils

PAUL SCHERRER INSTITUT



Douglas Araujo on behalf of the CHART Team :: Paul Scherrer Institute

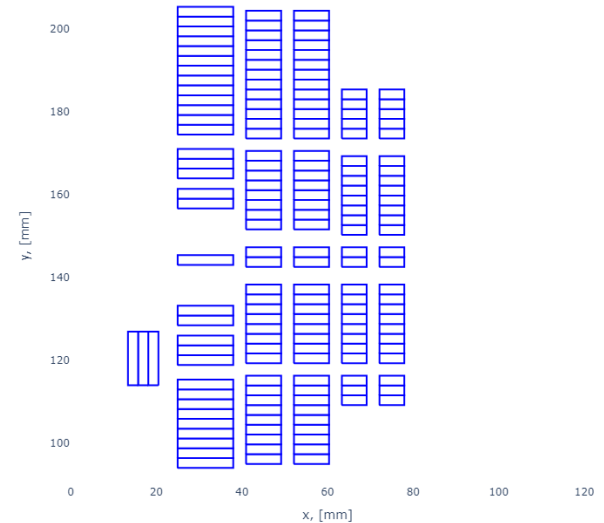
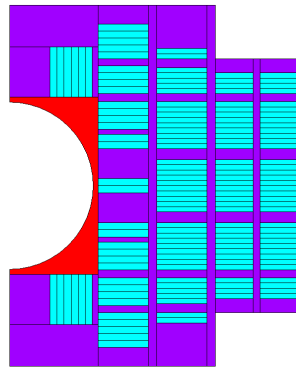
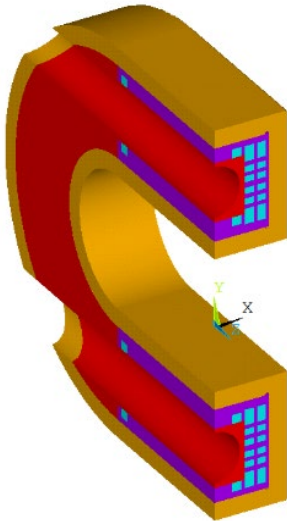
# Stress-Managed Asymmetric Common-Coils (SMACC) Conceptual Design

3<sup>rd</sup> Joint Common-Coils Meeting

Work supported by the Swiss State Secretariat for Education, Research and Innovation SERI.  
This work was performed under the auspices and with support from the Swiss Accelerator Research and Technology (CHART) program

In respect to a standard common-coils magnet, we would like to propose improvements on how to:

- deal with high Lorentz forces
- simplify the common-coils architecture for accelerator magnets allowing a full common coils architecture and reacting & winding

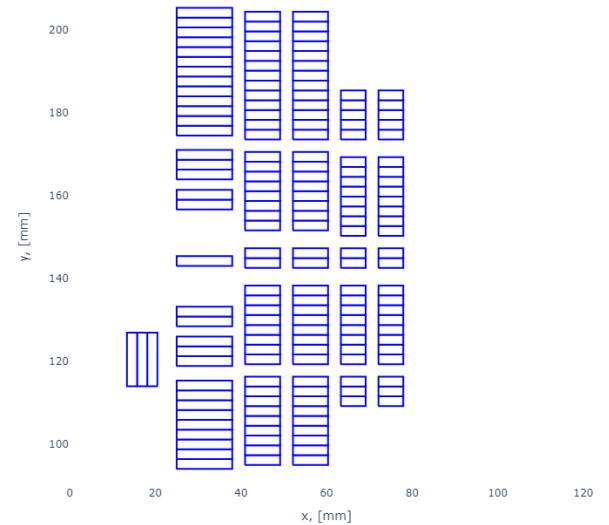
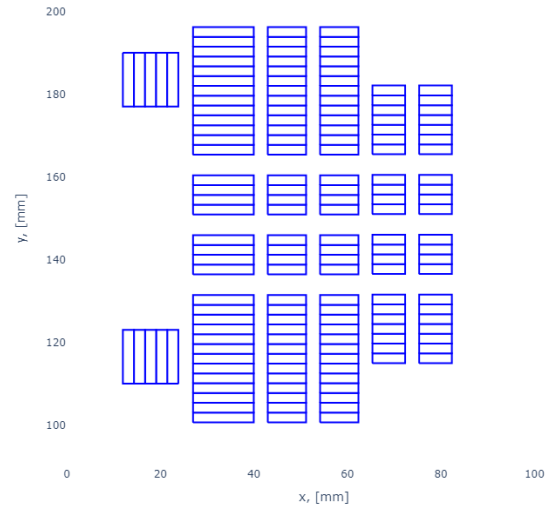
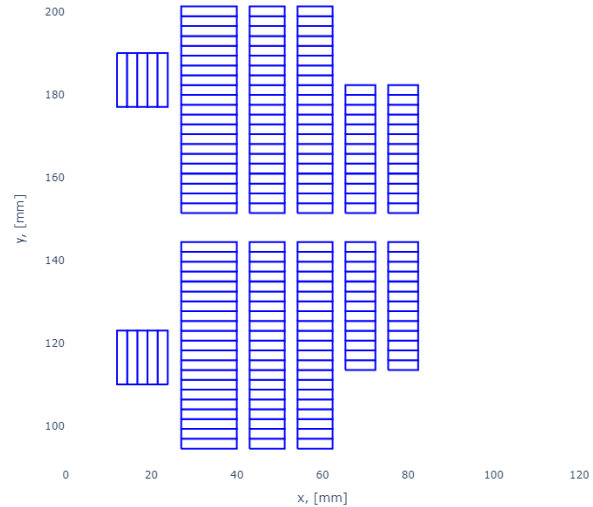


Let's consider two typical common-coils turns distribution, with racetracks on the top and bottom of apertures for field quality correction (a and b). C shows a third design without racetracks / clover-leaf coils, with an additional common-coil on the hard-way bend direction.

a: racetracks / clover-leaf coils and wide blocks

b: racetracks / clover-leaf coils and thin blocks

c: only common-coils and thin blocks

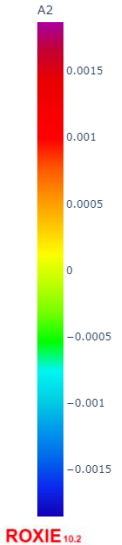
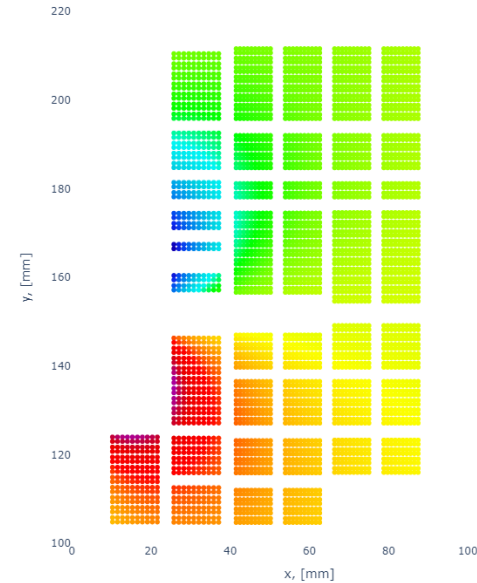
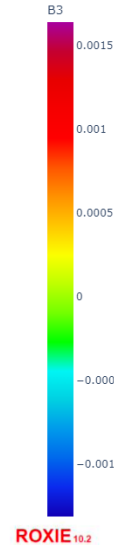
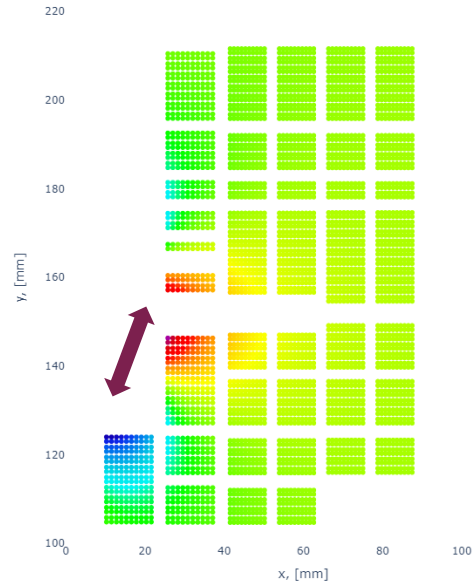
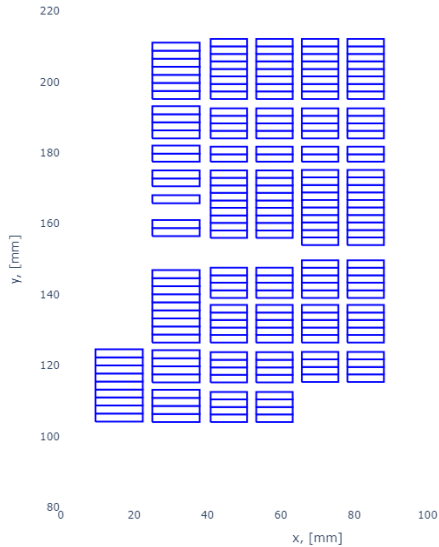


We can further simplify option C, by having only easy-way bend common-coils

Layers 1 and 2 with 21 x 1.1 mm RRP® strand cu/noCu 0.9 and layers 3 to 6 with 18 x 1.0 mm RRP® strand cu/noCu 1.3 for protection purpose.

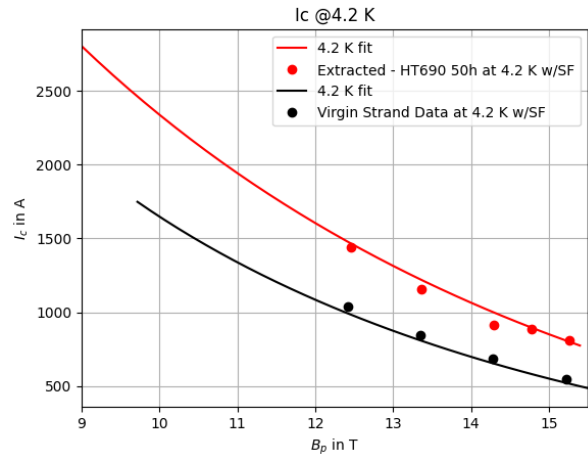
**b3** & **a2** compensation

Layers: 1 2 3 4 5 6

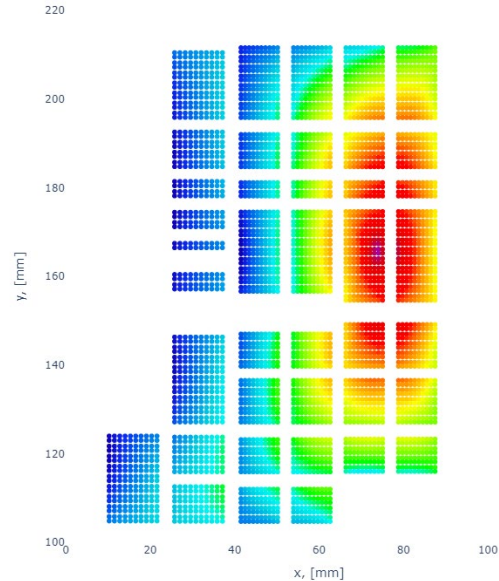


# Magnet Parameters

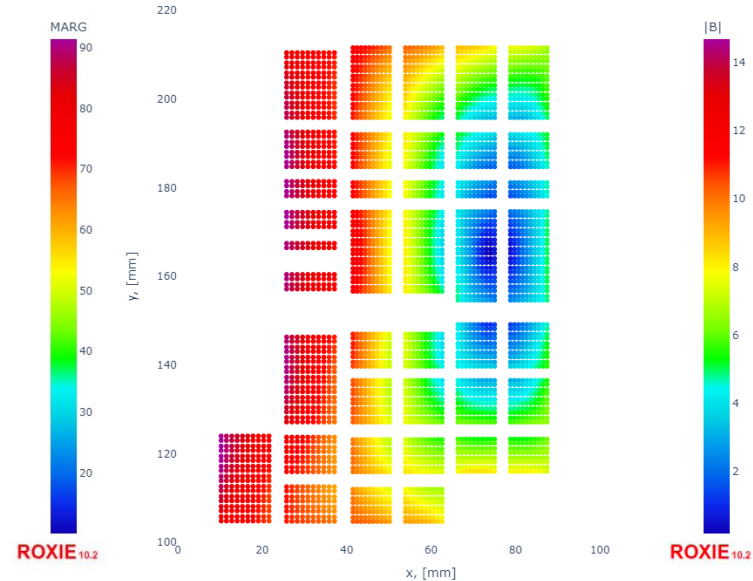
Ribs and spar thickness were optimized for mechanics and to have the **same margin in layers 1, 2 and 3**.  
Field quality is **< 15 units spread between injection and 14 T (10% margin at 4.2 K) nominal field operation**  
and **< 15 units at nominal (to be further optimized after the final cable definition)**.



**High-Field and Low-Field strand fitting**



D. M. Araujo





# Cross-Section

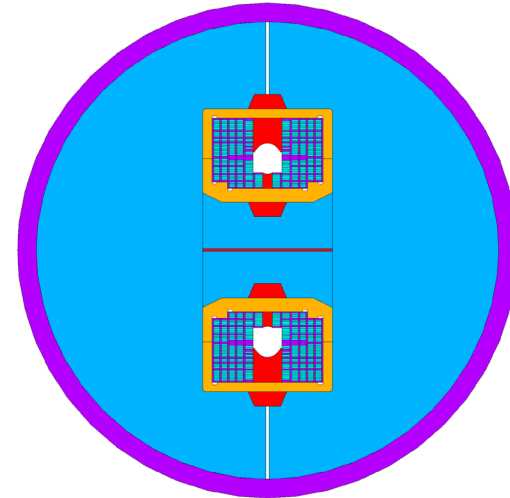
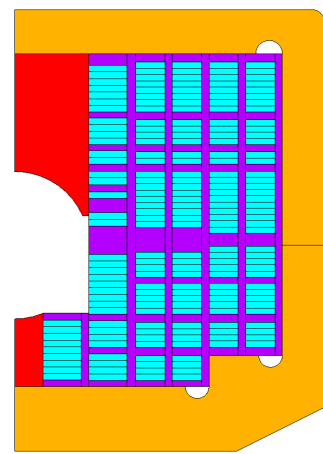
The asymmetric common-coils magnet was designed with a intra-beam distance of 300 mm, 50 mm **bore**, **yoke** diameter of 740 mm and 30 mm thick stainless steel **shell**.

The magnet has 4 different types of coils (layer 1, layer 2, layer 3,4 and layer 5,6) and **12 coils in total (for a double aperture magnet)**. The coils are placed in the stress-management **formers**. The preload is transferred towards the inner-most layers through the **ribs**.

The massive **iron pole**, combined with the asymmetric concept, helps on the balance vertical force balance.

The load, due to Lorentz forces, is distributed between **pads** and **shell**, which limits the thickness of the **shell**.

The magnet concept is based on **bladder & keys technology** for room temperature preload. The structure is loaded, but thanks to the stress-management formers, **the coil stress after loading and after cooling is < 40 MPa**.



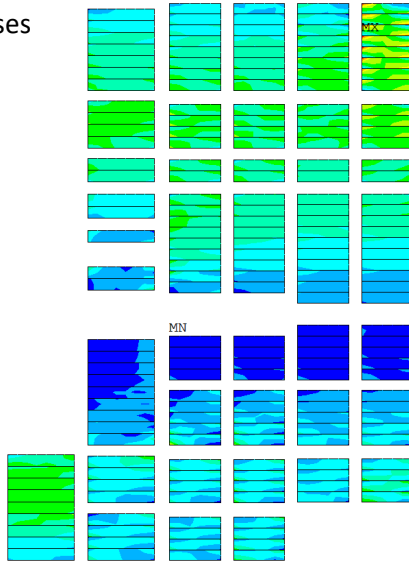
# Mechanical Analysis

Pre-load with 0.5 mm interference on the keys.

Low stress on coils: 37 MPa

**424 MPa** (compression) on the pads

Von-Mises

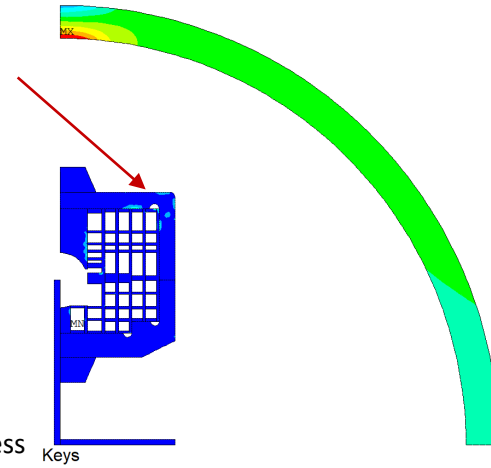


Keys

ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=1  
SUB =1  
TIME=1  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.552E-04  
SMN =71189.2  
SMX =.368E+08

Blue	.415E+07
Light Blue	.823E+07
Cyan	.123E+08
Green	.164E+08
Light Green	.205E+08
Yellow	.245E+08
Orange	.286E+08
Red-Orange	.327E+08
Red	.368E+08

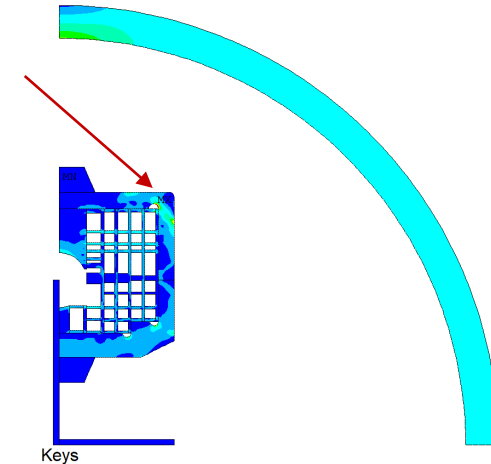
Maximum  
principal stress



ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=1  
SUB =1  
TIME=1  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.415E-03  
SMX =.238E+09

Blue	0
Light Blue	.264E+08
Cyan	.528E+08
Green	.792E+08
Light Green	.106E+09
Yellow	.132E+09
Orange	.158E+09
Red-Orange	.185E+09
Red	.211E+09
Dark Red	.238E+09

Von-Mises



ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=1  
SUB =1  
TIME=1  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.415E-03  
SMN =.253E-06  
SMX =.424E+09

Blue	.253E-06
Light Blue	.471E+08
Cyan	.941E+08
Green	.141E+09
Light Green	.188E+09
Yellow	.235E+09
Orange	.282E+09
Red-Orange	.329E+09
Red	.377E+09
Dark Red	.424E+09



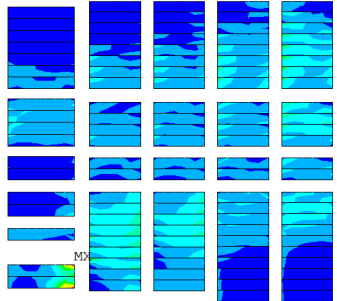
# Mechanical Analysis

Pre-load with 0.5 mm interference on the keys and cooling-down.

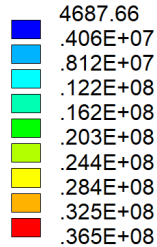
Low stress on coils: 37 MPa

**647 MPa** (compression) on the pads

Von-Mises

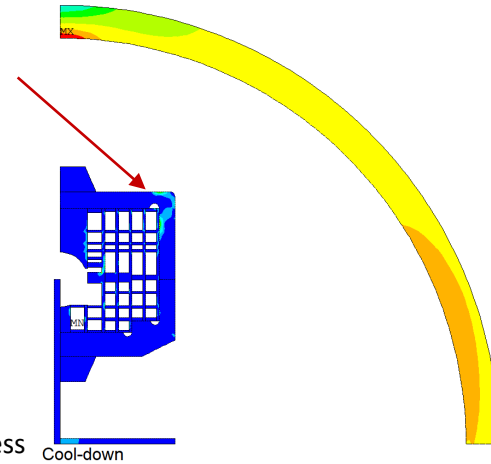


ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=2  
SUB =1  
TIME=2  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.603E-03  
SMN =4687.66  
SMX =.365E+08

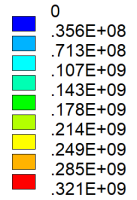


Cool-down

Maximum principal stress



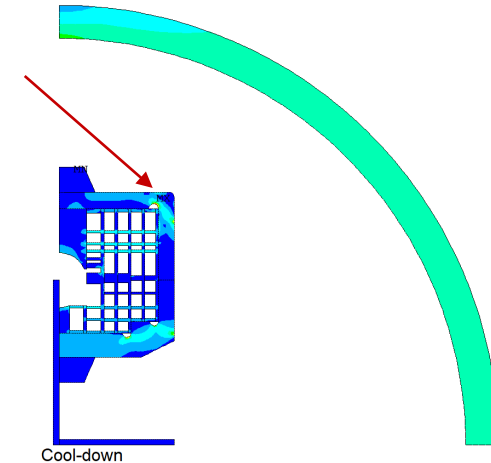
ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=2  
SUB =1  
TIME=2  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.974E-03  
SMX =.321E+09



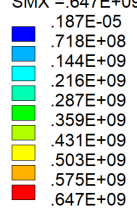
Blue	0
Light Blue	.356E+08
Cyan	.713E+08
Green	.107E+09
Light Green	.143E+09
Yellow-Green	.178E+09
Yellow	.214E+09
Orange	.249E+09
Red-Orange	.285E+09
Red	.321E+09

Cool-down

Von-Mises



ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=2  
SUB =1  
TIME=2  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.974E-03  
SMN =.187E-05  
SMX =.647E+09



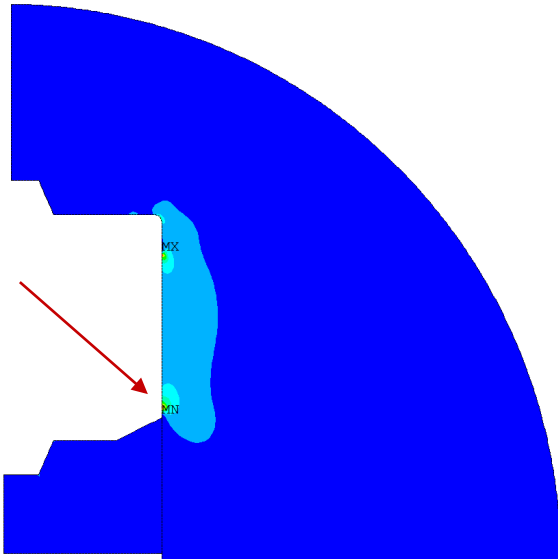
Blue	.187E-05
Light Blue	.718E+08
Cyan	.144E+09
Green	.216E+09
Light Green	.287E+09
Yellow-Green	.359E+09
Yellow	.431E+09
Orange	.503E+09
Red-Orange	.575E+09
Red	.647E+09

Cool-down

Pre-load with 0.5 mm interference on the keys and cooling-down.

Stress on iron: **487 MPa in one node**, other else < 200 MPa

Von-Mises



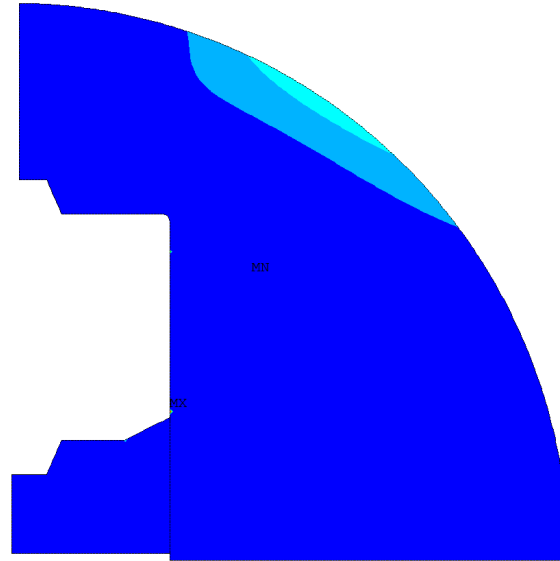
Cool-down

ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=2  
SUB =1  
TIME=2  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.919E-03  
SMN =836.328  
SMX =.487E+09

836.328
.541E+08
.108E+09
.162E+09
.216E+09
.270E+09
.325E+09
.379E+09
.433E+09
.487E+09

D. M. Araujo

Maximum principal stress



Cool-down

ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=2  
SUB =1  
TIME=2  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.919E-03  
SMX =.109E+09

0
.121E+08
.242E+08
.362E+08
.483E+08
.604E+08
.725E+08
.846E+08
.966E+08
.109E+09

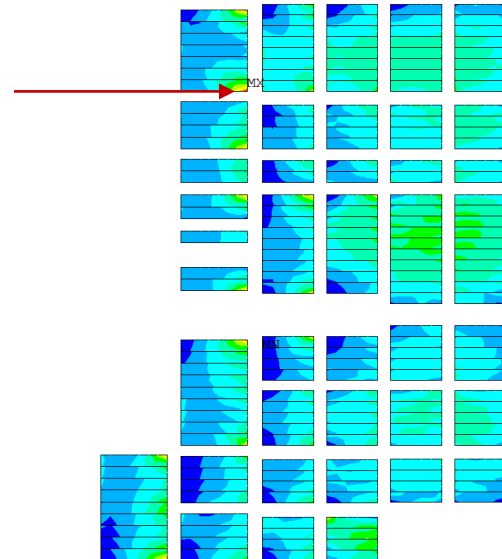
14 T operation (10% margin at 4.2 K)

Stress on coils: **128 MPa on corners**, other else  
< 100 MPa

15.1 T operation (10% margin at 1.9 K)

Stress on coils: **143 MPa on corners**, other else  
< 110 MPa

Von-Mises



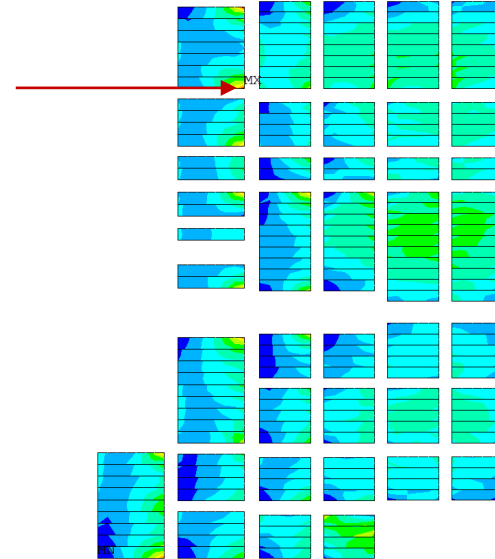
Nominal field

ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=3  
SUB =1  
TIME=3  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.648E-03  
SMN =492913  
SMX =.128E+09  
492913  

Blue	.146E+08
Light Blue	.288E+08
Cyan	.429E+08
Green	.570E+08
Light Green	.712E+08
Yellow-Green	.853E+08
Yellow	.994E+08
Orange	.114E+09
Red	.128E+09

D. M. Araujo

Von-Mises



Nominal field

ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=3  
SUB =1  
TIME=3  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.673E-03  
SMN =997664  
SMX =.143E+09  
997664  

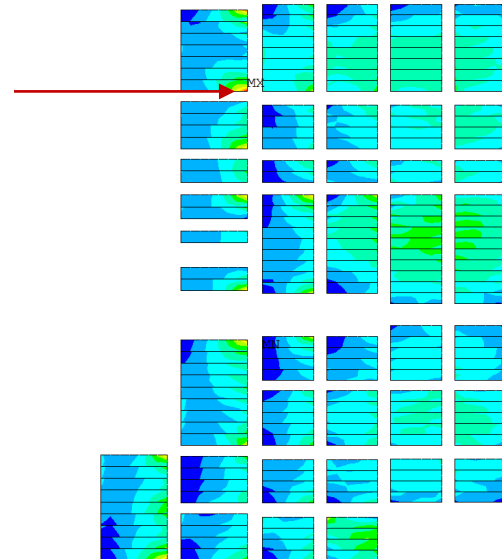
Blue	.168E+08
Light Blue	.325E+08
Cyan	.483E+08
Green	.641E+08
Light Green	.799E+08
Yellow-Green	.956E+08
Yellow	.111E+09
Orange	.127E+09
Red	.143E+09

14 T operation (10% margin at 4.2 K)

Stress on coils: **128 MPa on corners**, other else  
< 100 MPa

< 30% engineering margin on the peak of stress  
regions.

Von-Mises

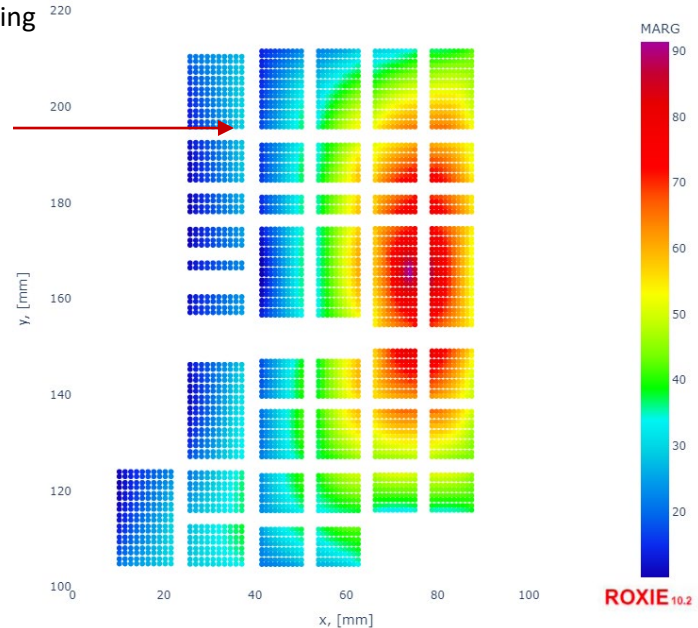


Nominal field

ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=3  
SUB =1  
TIME=3  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.648E-03  
SMN =492913  
SMX =.128E+09  
492913  
.146E+08  
.288E+08  
.429E+08  
.570E+08  
.712E+08  
.853E+08  
.994E+08  
.114E+09  
.128E+09

D. M. Araujo

Engineering  
margin



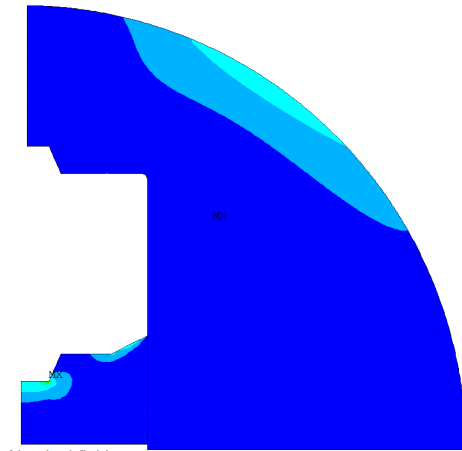
15.1 T operation

Peak of **692 MPa** on the formers

Stress on iron: **526 MPa in one node**, other else < 350 MPa

ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=3  
SUB =1  
TIME=3  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .001061  
SMX = .257E+09

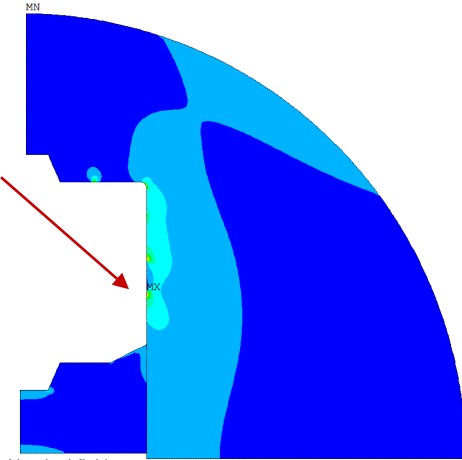
0
.285E+08
.570E+08
.855E+08
.114E+09
.143E+09
.171E+09
.200E+09
.228E+09
.257E+09



Nominal field

ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=3  
SUB =1  
TIME=3  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .001061  
SMN = 55132.8  
SMX = .526E+09

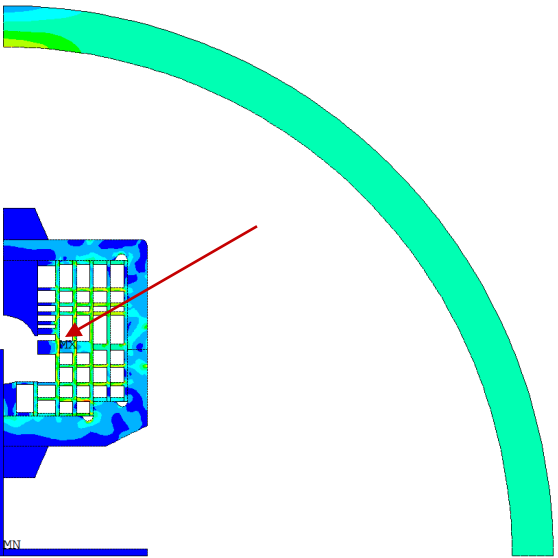
55132.8
.584E+08
.117E+09
.175E+09
.234E+09
.292E+09
.350E+09
.409E+09
.467E+09
.526E+09



Nominal field

ANSYS 2021 R1  
Build 21.1  
NODAL SOLUTION  
STEP=3  
SUB =1  
TIME=3  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX = .001104  
SMN = .724E-07  
SMX = .692E+09

.724E-07
.769E+08
.154E+09
.231E+09
.307E+09
.384E+09
.461E+09
.538E+09
.615E+09
.692E+09



Nominal field



## Introduction of

- ... Stress-Managed  
Common-Coils Concept
- ... Asymmetric Common-  
Coils Concept

## Possible advantages are

- ... Lower margin operation  
due to the low stress on  
high-field regions
- ... Pure common-coils (no  
need for racetrack /  
clover-leaf/... correctors)
- ... Possibility of  
implementing Reaction  
& Winding technique

