PAUL SCHERRER INSTITUT PSI

Swiss Accelerator Research and Technology

HFM High Field Magnets

D. Araujo, B. Auchmann, A. Brem, T. Michlmayr, C. Müller and A. Haziot :: Paul Scherrer Institute

Status of Subscale Stress-Managed Common-Coils Manufacturing and on the SMACC conceptual design

HFM Forum

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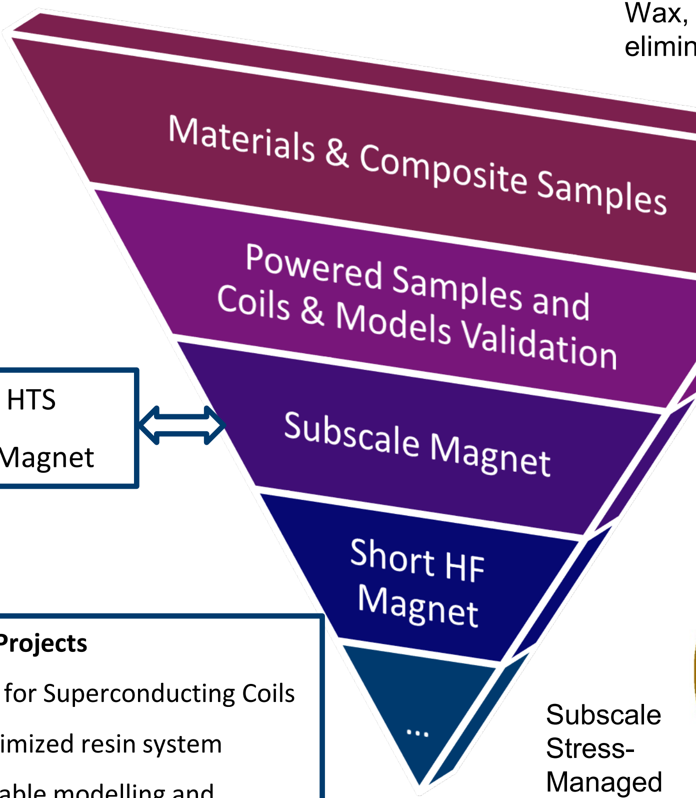
This work was performed under the auspices and with support from the Swiss Accelerator Research and Technology (CHART) program

LTS and Hybrid LTS/HTS Roadmap



Hybrid HTS

Subscale Magnet

CHART Mag Projects

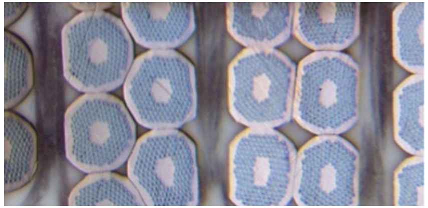
MagAM: AM for Superconducting Coils

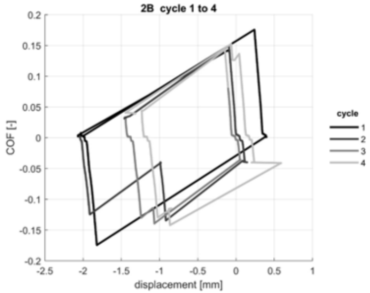
MagRes: Optimized resin system

MagComp: Cable modelling and caracterization

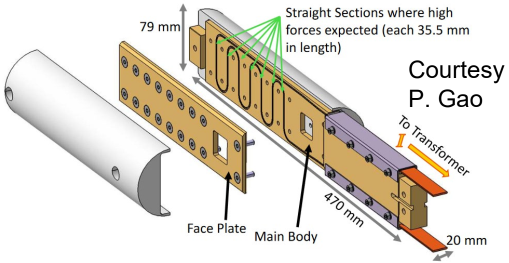
MagNum: Modelling & Optimization

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

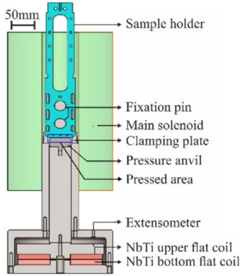




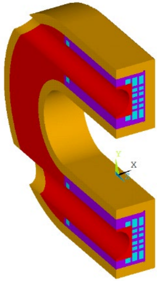
BOX: Single-turn wax impregnated sample, PSI & U. Twente

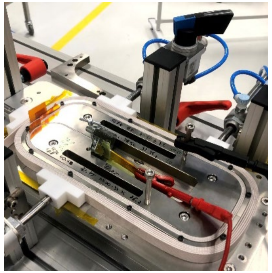


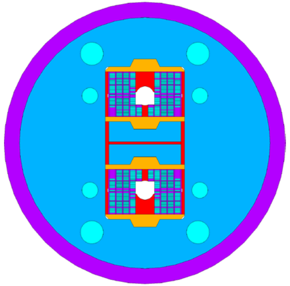
Courtesy P. Gao



Subscale Stress-Managed Common-coils





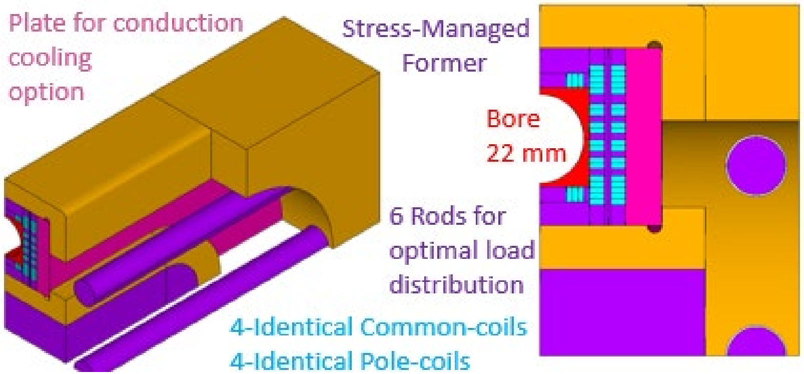


Stress-Managed Asymmetric Common Coils

D. M. Araujo

Subscale LTS (Nb_3Sn) Magnet

- Validating manufacturing process and introducing advanced concepts: coil pre-load free, at room temperature; stress-management structure and splicing on the low-field region.
- Fast turn-around platform for testing matrix systems; protection concepts and cooling options.
- Hybrid magnet with LTS (Nb_3Sn) Common-Coils and HTS racetracks
- LTS (Nb_3Sn) conductor manufactured by LBNL (cct subscale cable)

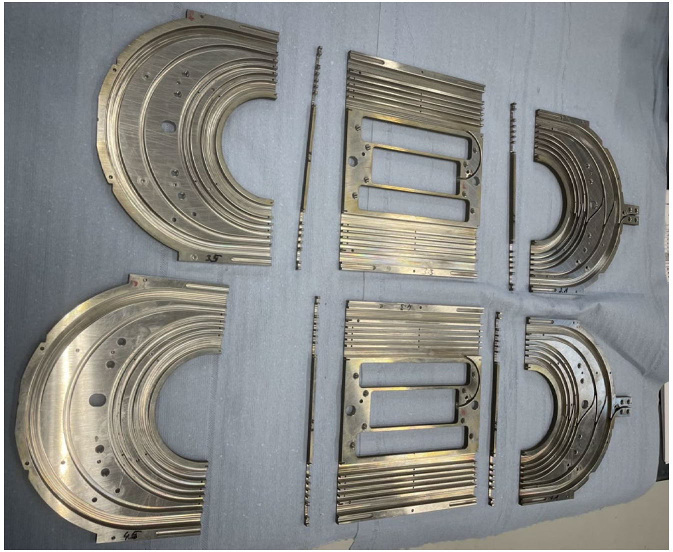


Magnet parameters for testing all coils or the common-coils. The coils straight section is 150 mm. The values refer to the fitted wire Ic curve at 4.2 K values.

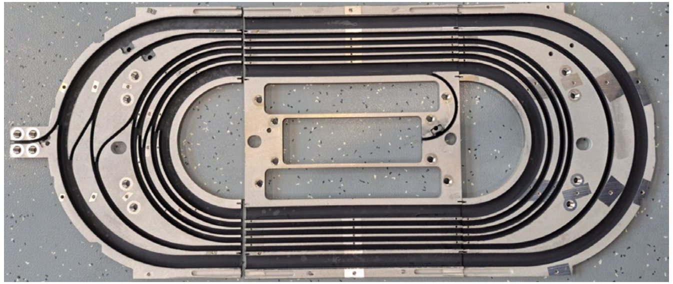
Parameter	All coils	CCs
B_{0_ss} in T	5.15	5.1
B_{peak_ss} in T	6.45	6.3
I_{ss} in kA	8.25	9.2
E_{mag_ss} in kJ	15.2	16.4

Subscale – Former preparation

5 pieces former



Dip coating



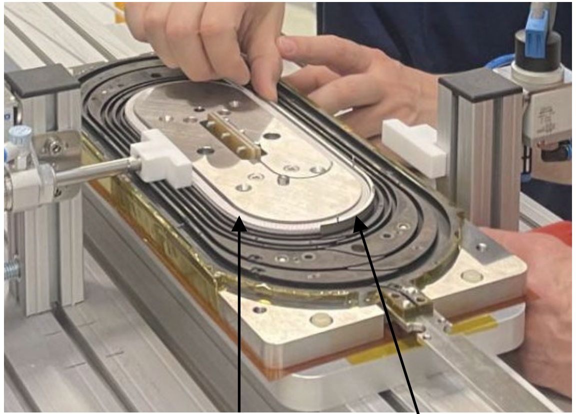
Ceramic glazing

Subscale – Winding

spool

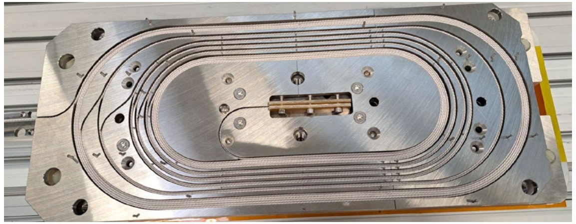
former

Rotating beam



After 1st coil block

rib



Before pushing down

After pushing down

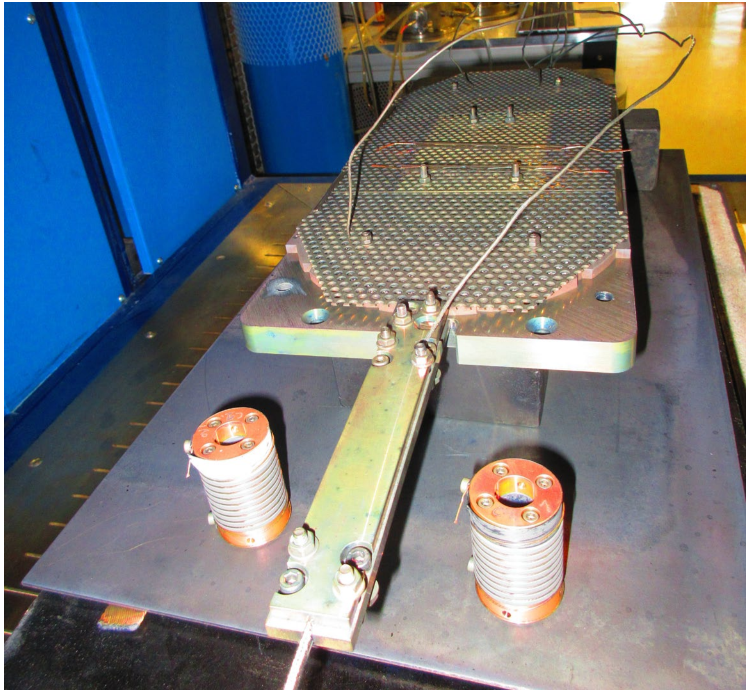
Subscale – Winding: not proud of...

Re-machining former holes during the winding

Cutting a screw because it couldn't be removed

etc

Subscale: Reaction



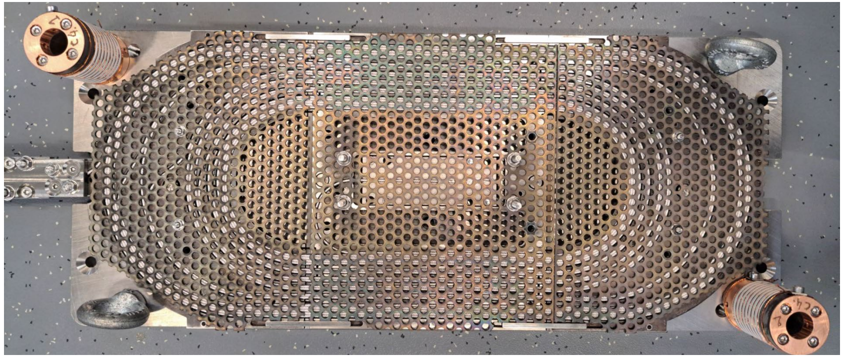
Coil 1 – former 2

Oxidation on barrels

RRR measurement of witness samples

145 and 182 for the extracted strands

Status: waiting for barrels Ic measurements before the coil – former 1 reaction is launched

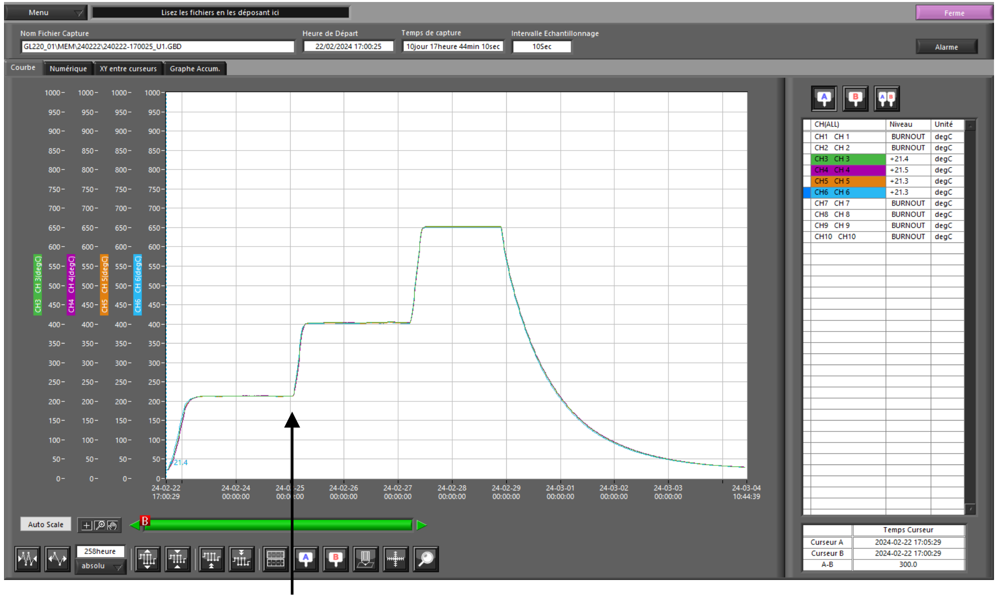


Coil 4 – former 4

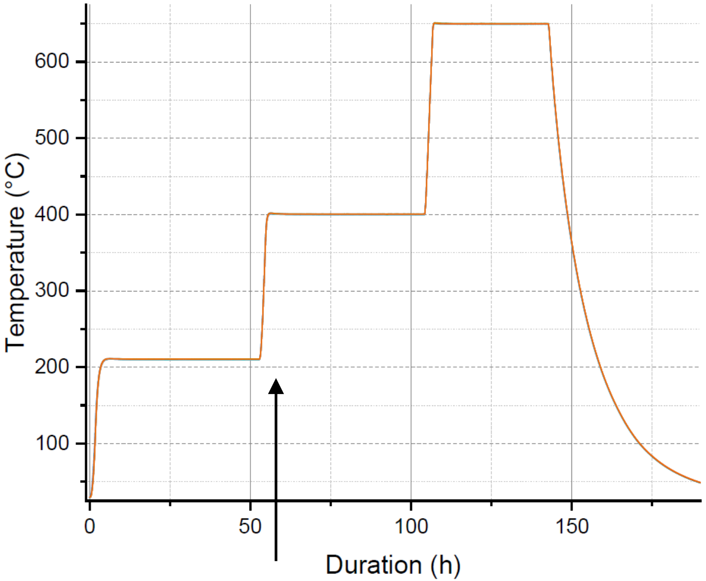
Subscale: Reaction

CERN/927

PSI CHART/MagDev

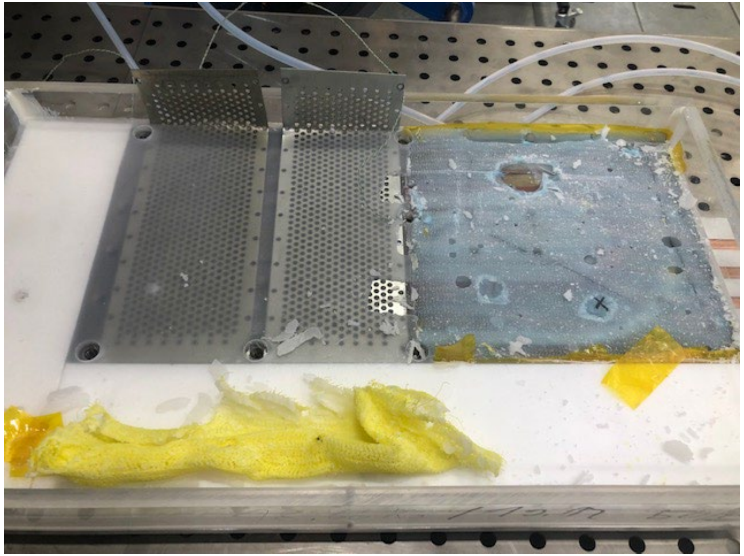


~ 50 °C/h



~ 100 °C/h

Subscale: Impregnation trials



One-piece mold with insulated copper cable

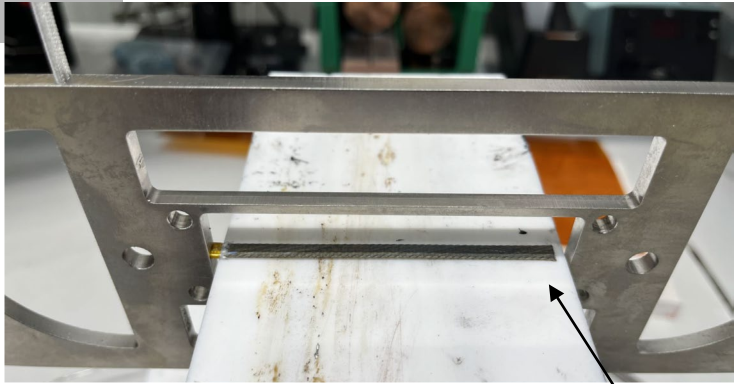
Metallic and non-metallic mesh trials

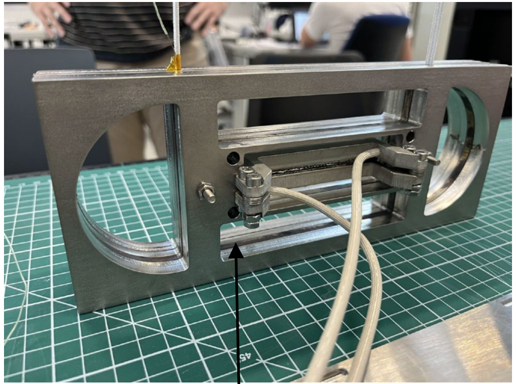
Controlled mold heaters and cooling circuit

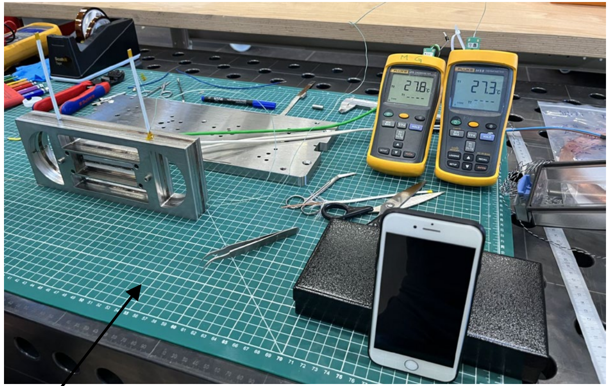
Matrix: Filled Wax

Subscale: Splicing trials

Intra-layer splice





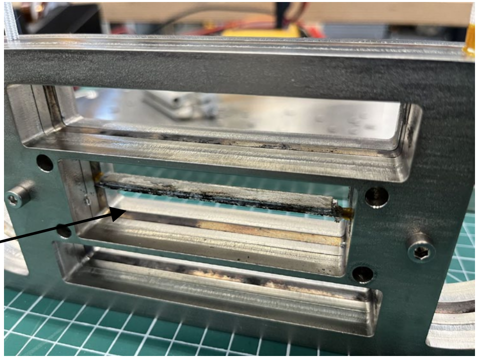


Heaters

Test setup

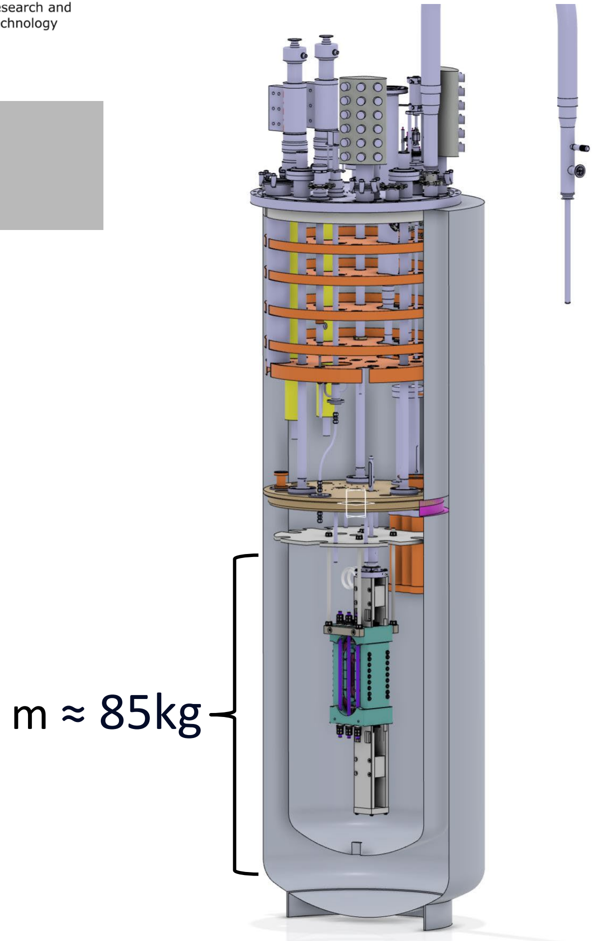
splice mock-up

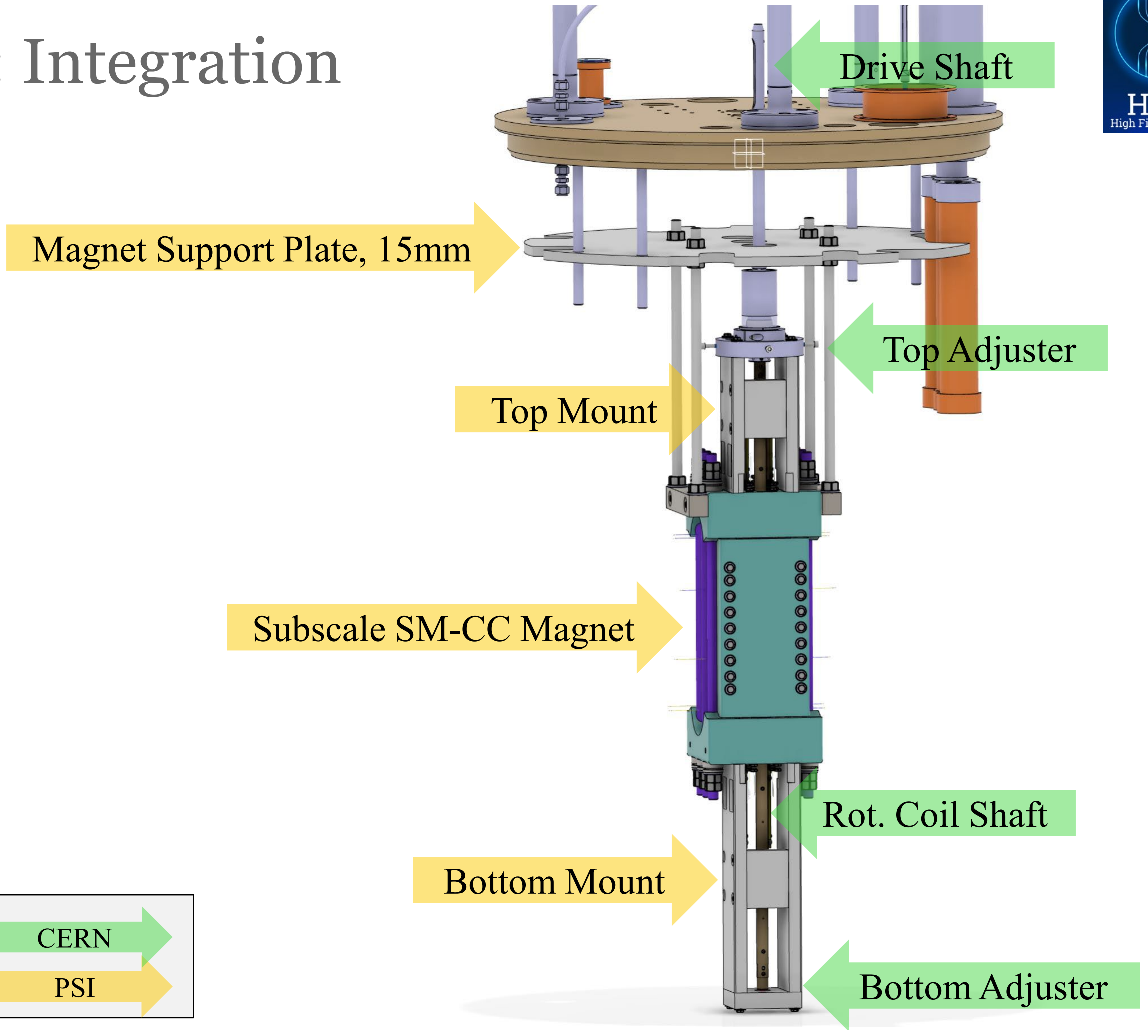
NbTi pre-thinned



After splicing

Subscale: Integration





CERN
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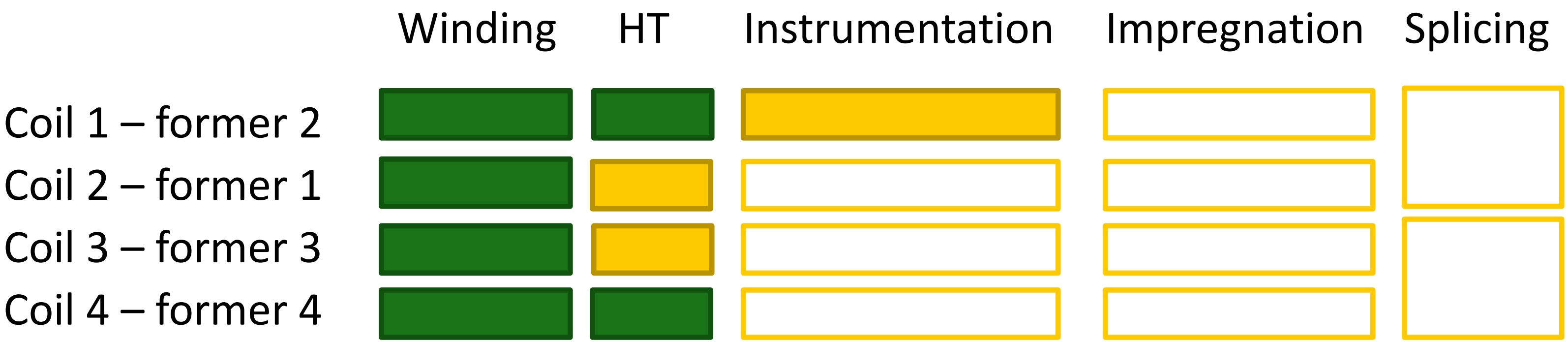
Subscale: coils manufacturing status, components delivery date and final assembly



Magnet structural Components delivery date	May/June 2024
Final assembly and pre-load	June 2024
Siegtal and rotating coil integration parts status	Finalizing the drawings

Acknowledgment

- CHART: B. Auchmann, A. Brem, T. Michlmayr, C. Müller, J. Schmidt
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- CERN: F-J. Mangiarotti, C. Petrone, J. Feuvrier, S. Russenschuck
- CERN: F-O. Pincot, J-C. Perez, A. Haziot, E. Todesco, A. Milanese
- CERN: L. Gentini

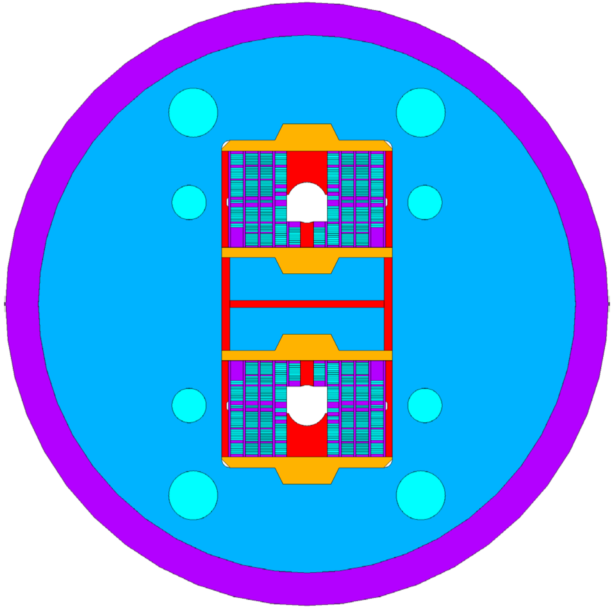
Stress-Managed Asymmetric Common-Coils (SMACC) - Cross-Section

The asymmetric common-coils magnet has an intra-beam distance of 250 mm, 50 mm **bore**, **yoke** diameter of 660 mm and 40 mm thick stainless-steel **shell.**

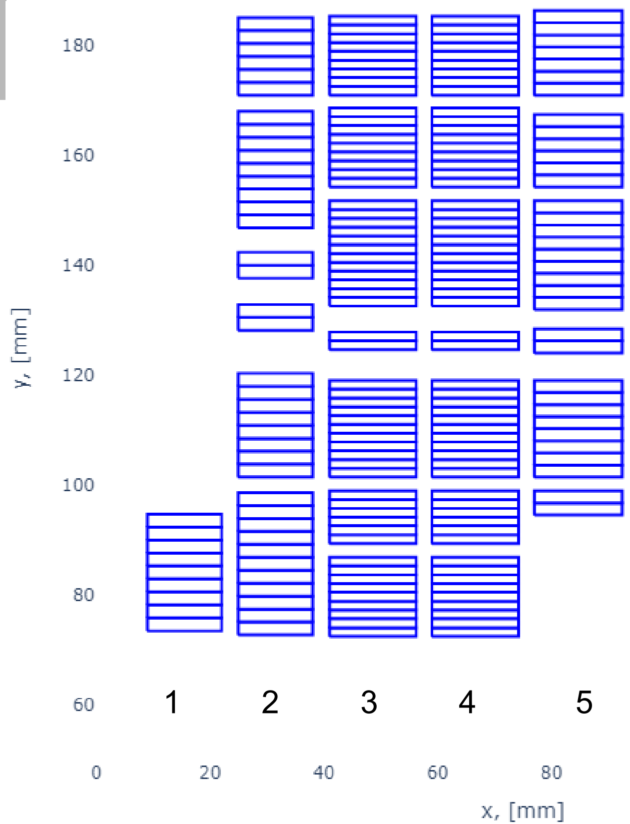
The magnet has 4 different types of coils (layer 1, layer 2, layer 3,4 and layer 5) and 10 coils in total (for a double aperture magnet). The coils are placed in the stress-management **formers**. The preload is transferred towards the inner-most layers through the **ribs**.

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

The magnet concept is based on bladder & keys technology for room temperature preload.



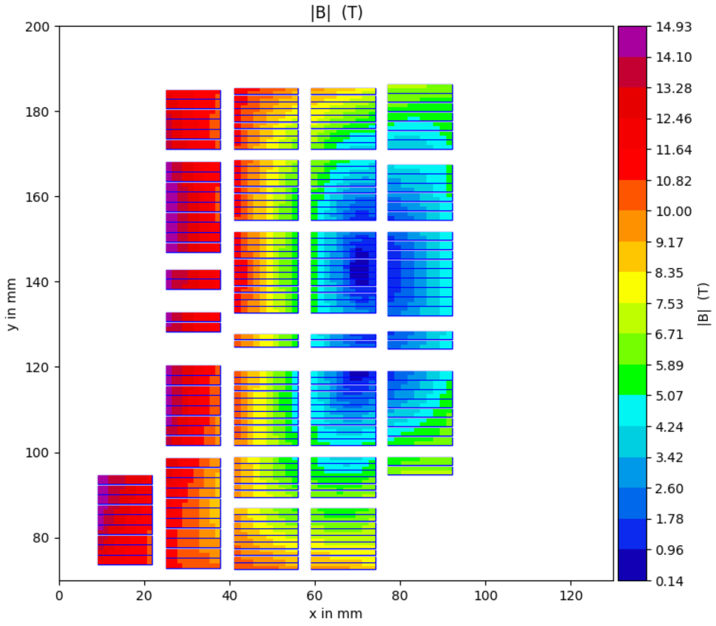
Stress-Managed Asymmetric Common-Coils (SMACC) – Hybrid Nb_3Sn / NbTi – v2

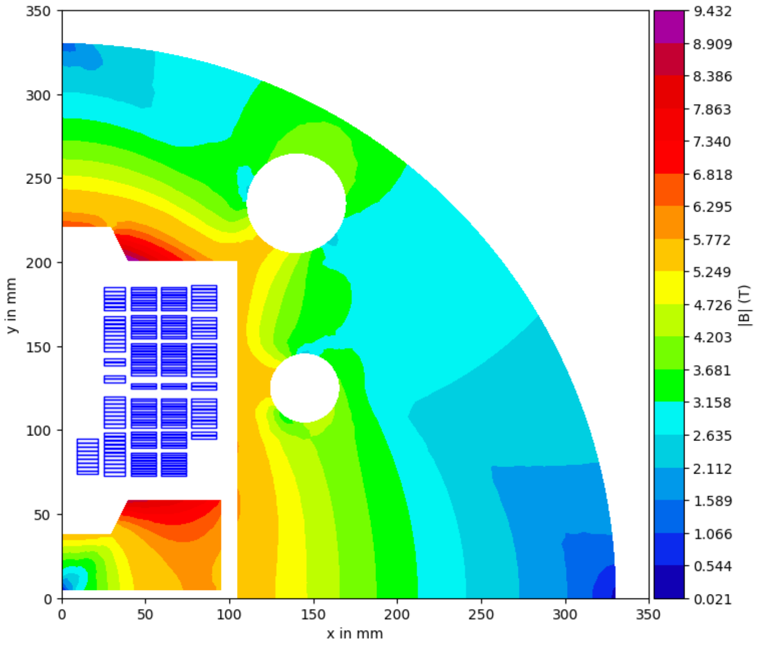


Layers	1	2	3/4	5
Wire type	Nb_3Sn RRP® 162/169	Nb_3Sn RRP® 162/169	Nb_3Sn RRP® 78/91	NbTi
N wire x dia in mm	21 x 1.1	21 x 1.1	40 x 0.7	28 x 1.065
Cu/nCu	0.9	0.9	1.2	1.0
Bare Cable dimensions in mm	12.74 x 2.06	12.74 x 2.06	14.94 x 1.3	15.10 x 1.90
Insulation thickness in mm	0.155	0.155	0.155	0.155
Number of turns	9	38	58/58	34

Stress-Managed Asymmetric Common-Coils (SMACC) – Hybrid Nb_3Sn / NbTi – v2 - 14 T

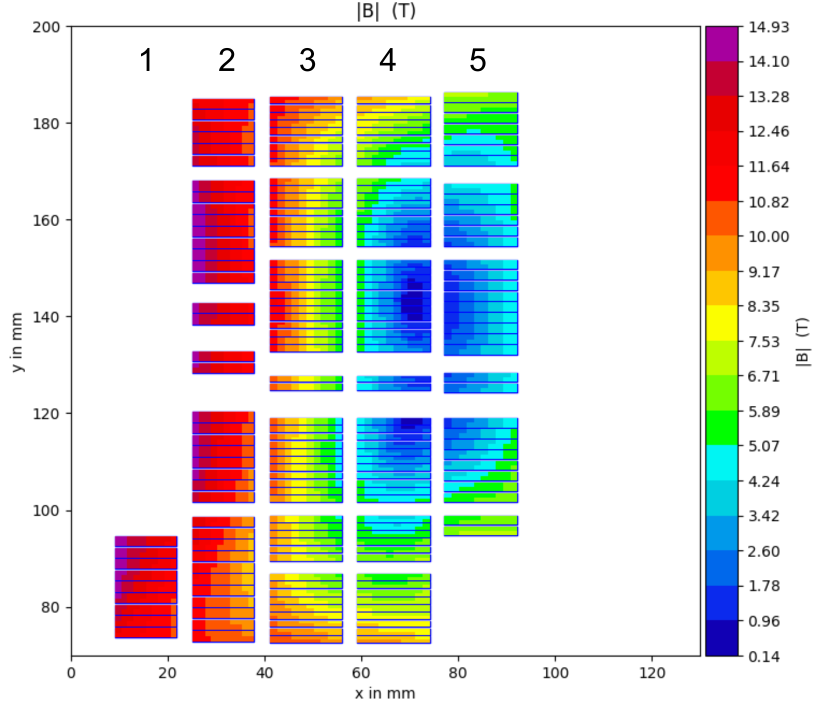
Ribs and spar thickness were optimized for mechanics. Field quality is < 20 units spread between injection (1 T) and nominal field 14 T operation and < 12 units at nominal (to be further optimized after the final cable definition). I_{op} = 12.48 kA





|B| including self-field

Stress-Managed Asymmetric Common-Coils (SMACC) – Hybrid Nb_3Sn / NbTi – v2

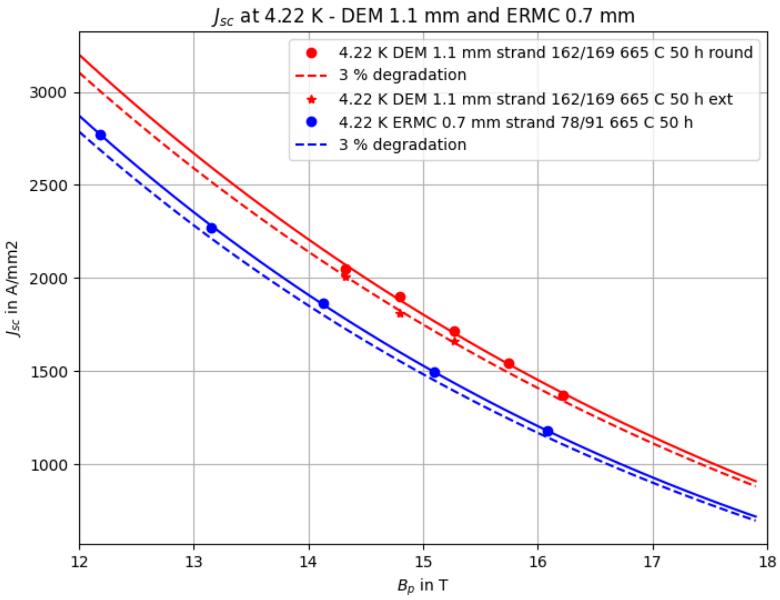


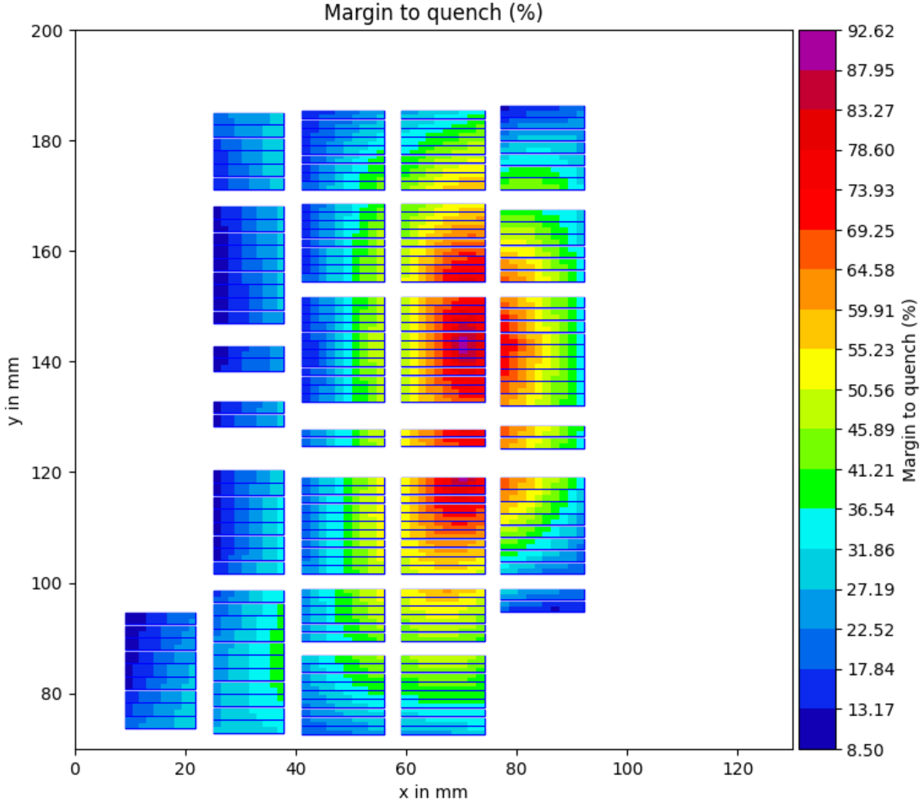
B_0 in T	B_{peak} in T	T_{op} in K	% Margin	I_{op} in kA
14	14.93	4.22	8.5	12.48

Layer	B_{peak} in T	% Margin	J_{sc} in A/mm²	J_{cu} in A/mm²	J_{eng} * in A/mm²
1	14.82	9.0	1188.2	1320.2	405.5
2	14.93	8.5			
3	11.64	13.4	1783.6	1486.3	511.8
4	9.43	25.7			
5	7.05	10.9	1000.7	1000.7	368.4

* Including insulation area

Stress-Managed Asymmetric Common-Coils (SMACC) – Hybrid Nb_3Sn / NbTi – v2 - 14 T





High-Field and Low-Field strand fitting

Protecting 15 m long magnet with 1x 100 mF, 2 kV CLIQ unit

Red: Negative initial CLIQ dI/dt

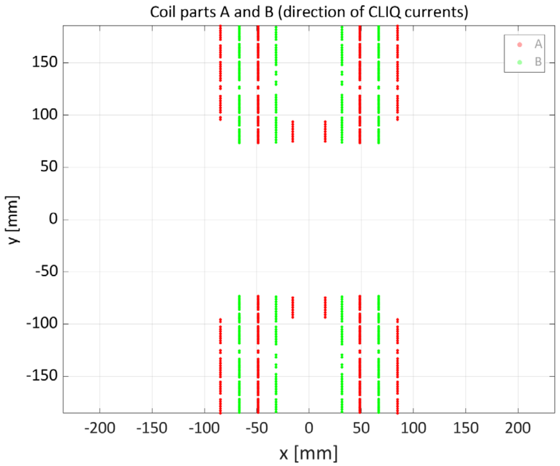
Green: Positive initial CLIQ dI/dt

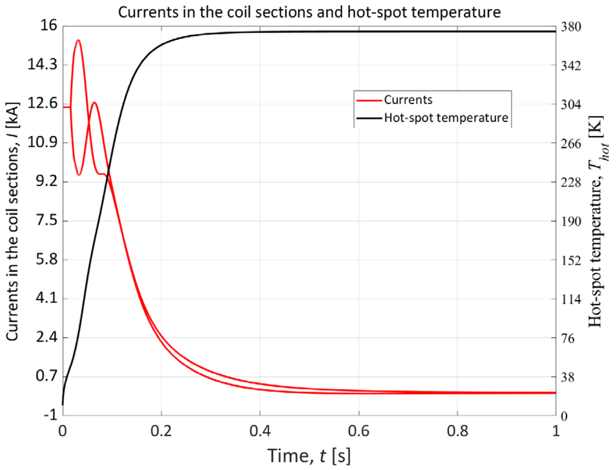
Currents vs time

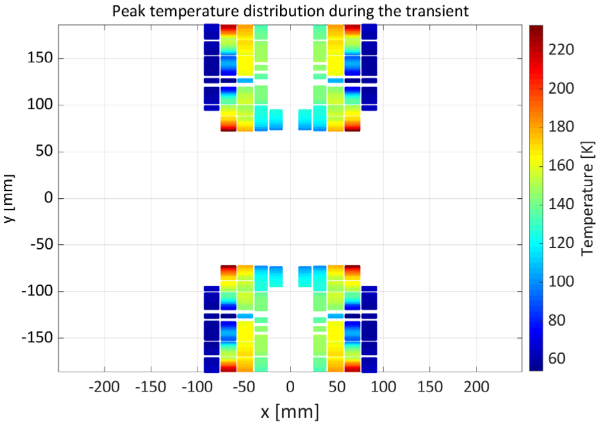
Hot-spot temperature vs time

Temperature in the turns

(hot-spot not shown here)





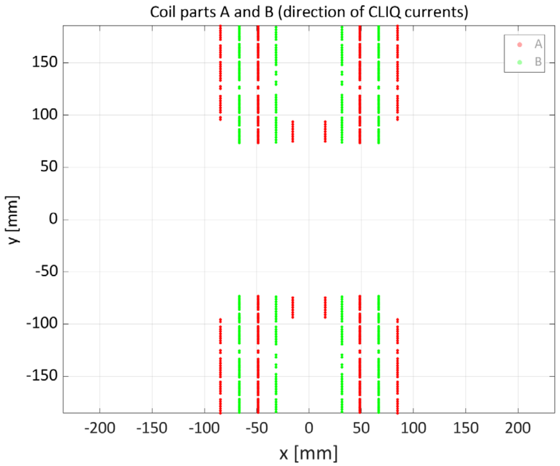


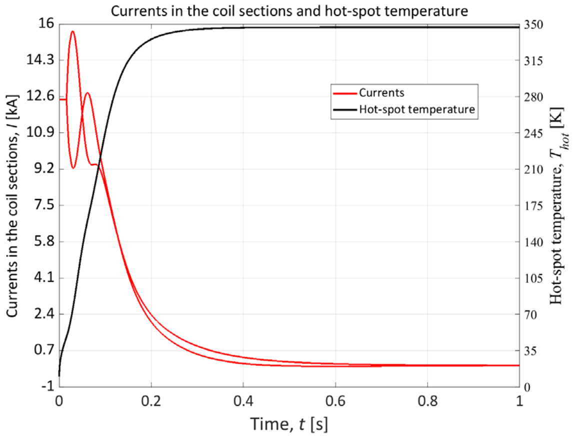
Hot-spot temperature	Peak voltage to ground	Peak CLIQ current
375 K	1950 V	5890 A

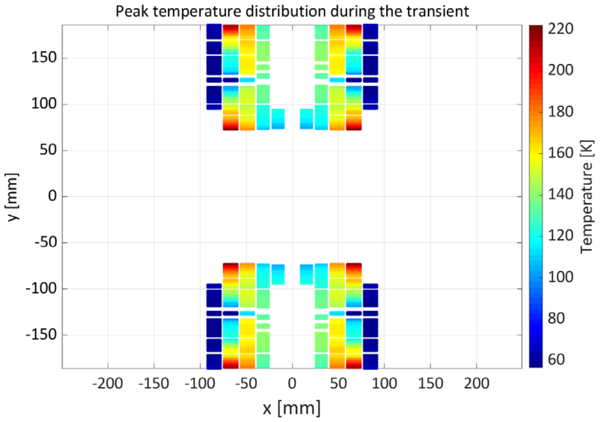
E. Ravaioli

Protecting 12 m long magnet with 1x 100 mF, 2 kV CLIQ unit

Red: Negative initial CLIQ dI/dt Green: Positive initial CLIQ dI/dt	Currents vs time Hot-spot temperature vs time	Temperature in the turns (hot-spot not shown here)







Hot-spot temperature	Peak voltage to ground	Peak CLIQ current
347 K	1790 V	6430 A

E. Ravaioli

Protecting 0.8 m long magnet with 1x 100 mF, 0.5 kV CLIQ unit

Red: Negative initial CLIQ dI/dt

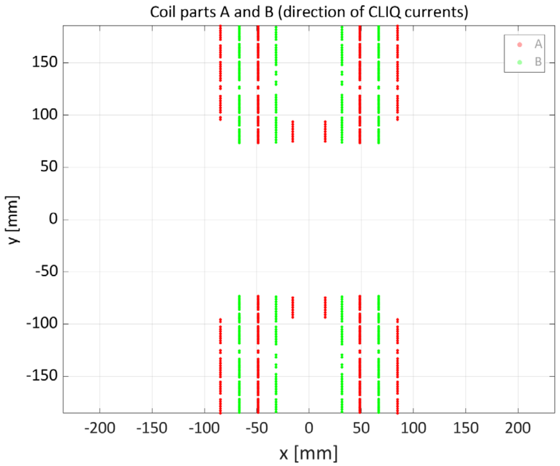
Green: Positive initial CLIQ dI/dt

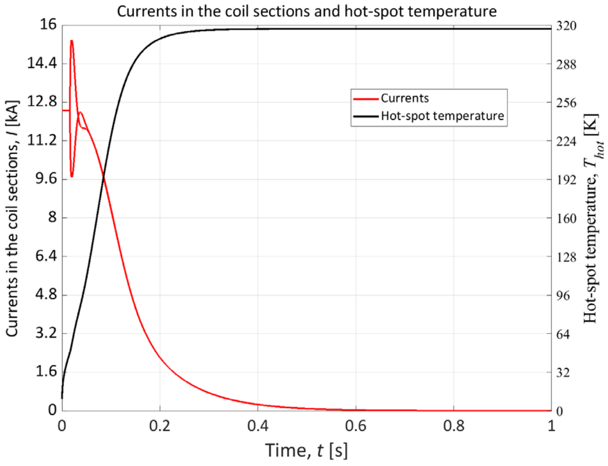
Currents vs time

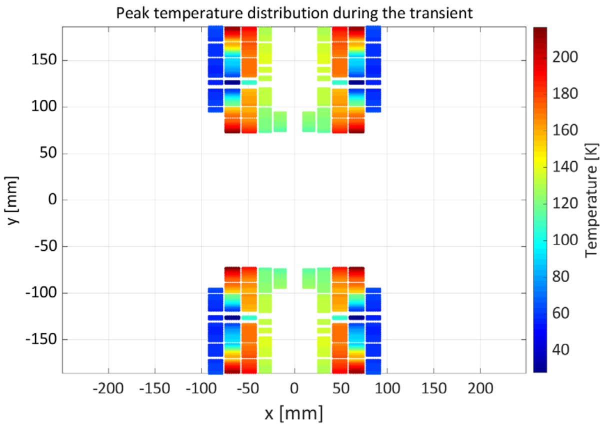
Hot-spot temperature vs time

Temperature in the turns

(hot-spot not shown here)







Hot-spot temperature	Peak voltage to ground	Peak CLIQ current
317 K	150 V	5680 A

E. Ravaioli

Mechanical Analysis

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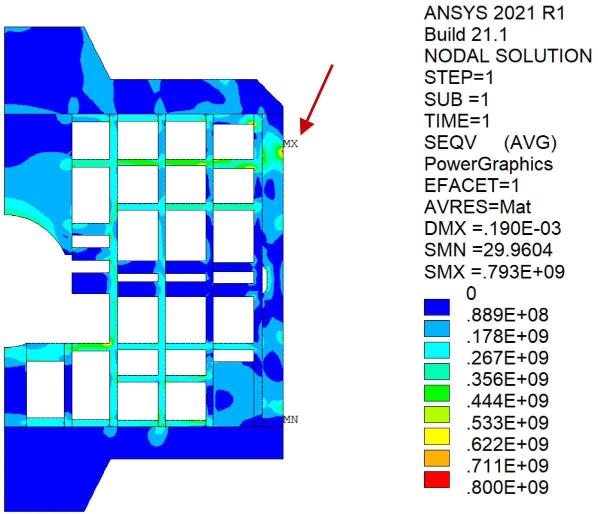
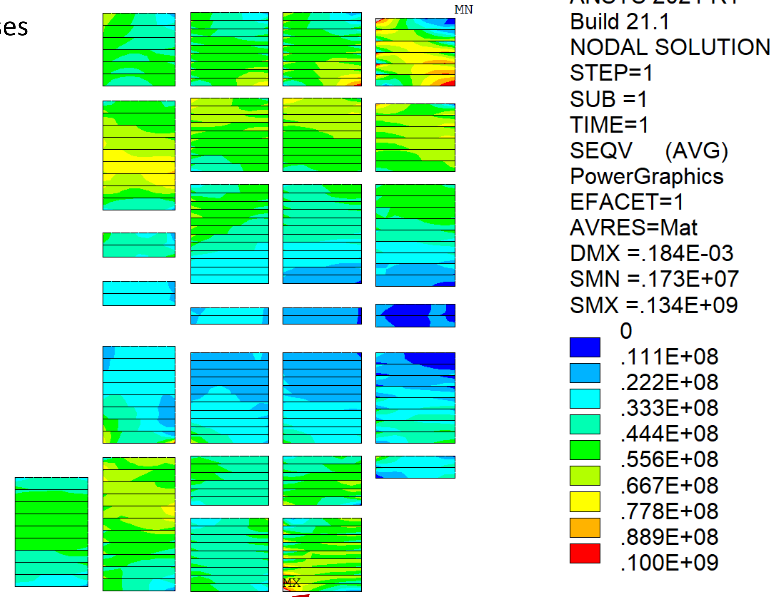
Pre-load with 0.75 mm interference on the keys.

Von-Mises



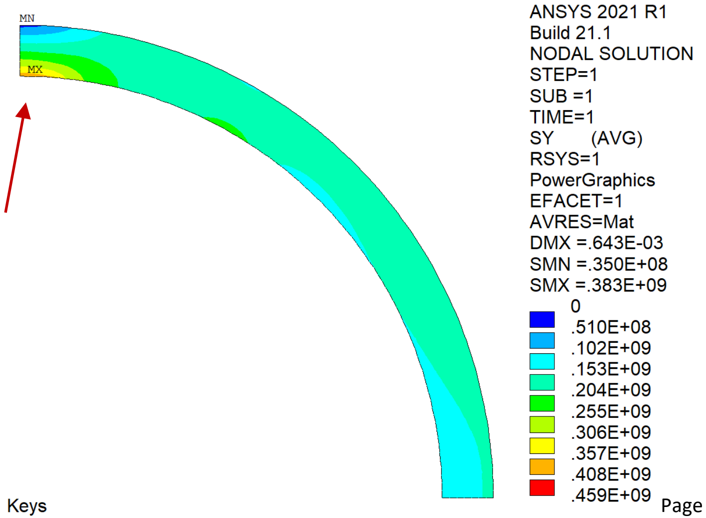
Von-Mises



Keys

Keys

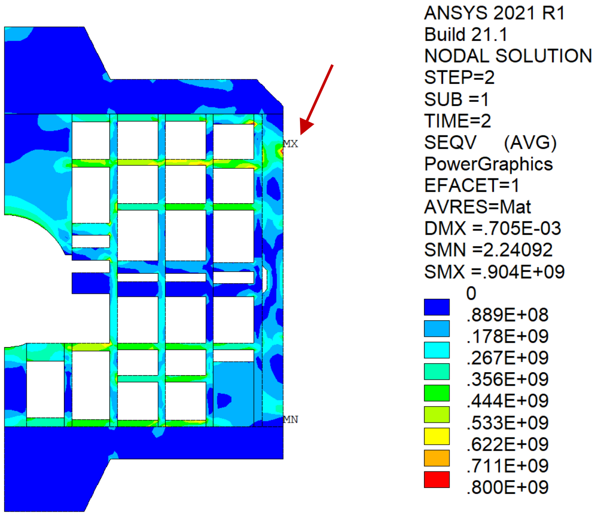
Hoop Stress



Keys

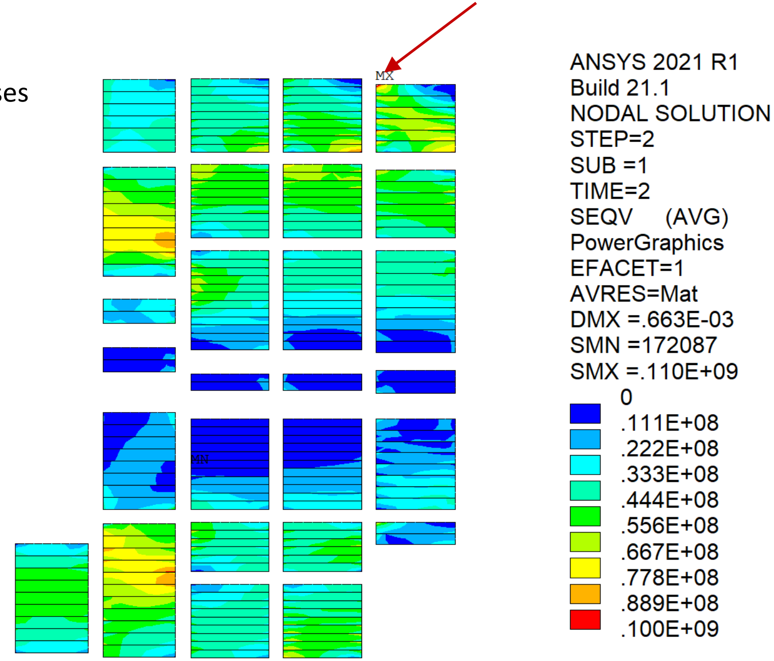
Mechanical Analysis

Von-Mises



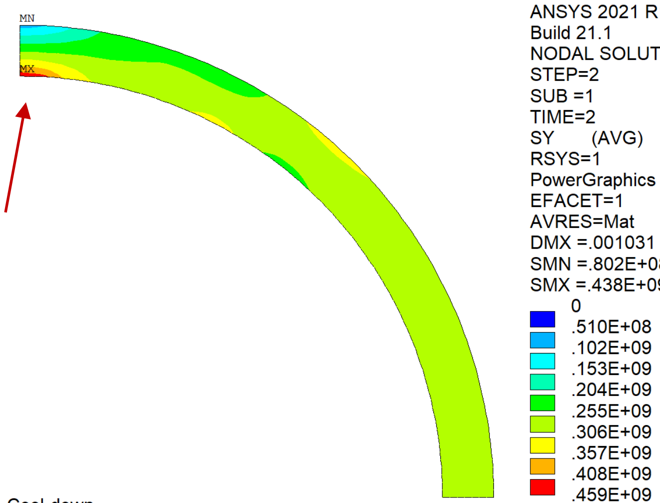
Cool-down

Von-Mises



Cool-down

Hoop Stress

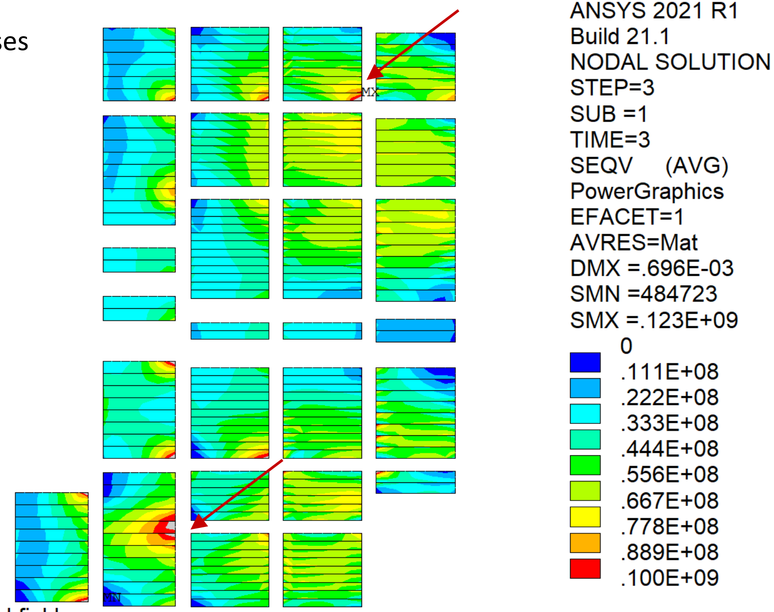


Cool-down

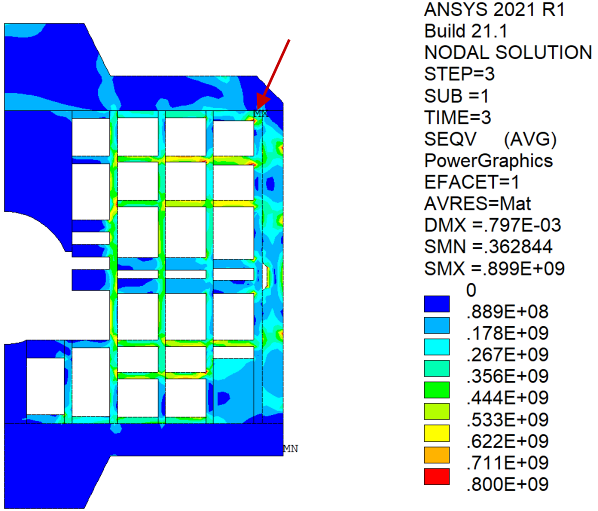
Mechanical Analysis

Von-Mises

Von-Mises

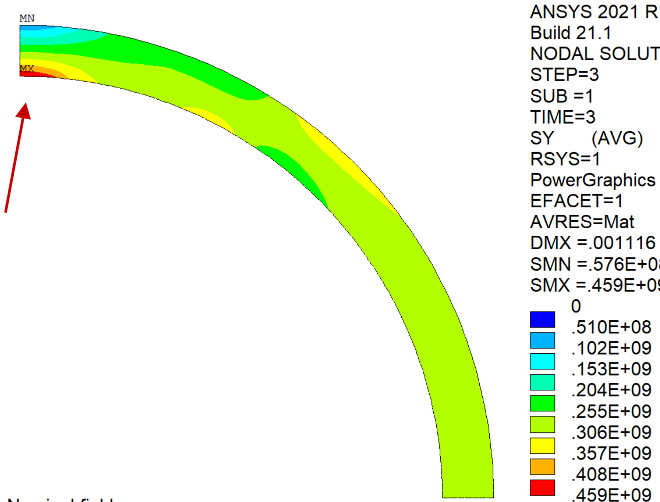


Nominal field



Nominal field

Hoop Stress



Nominal field

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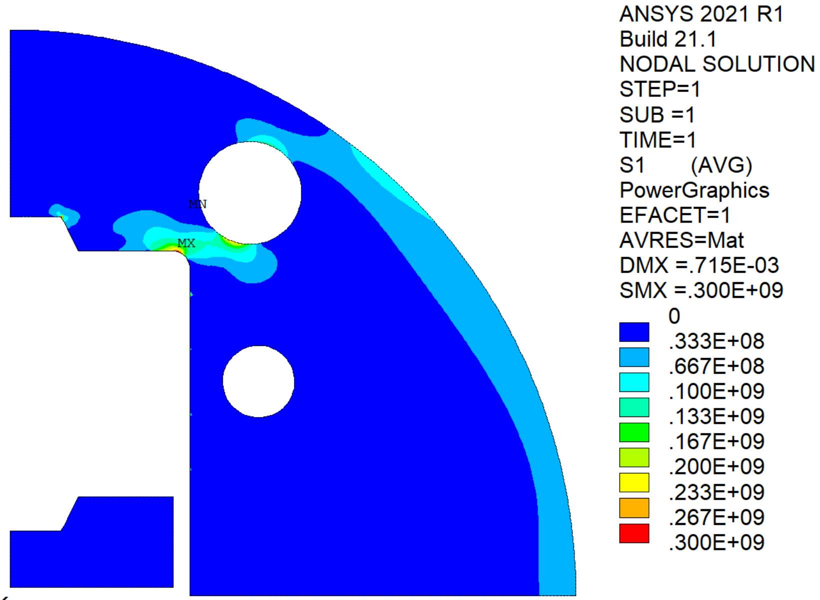
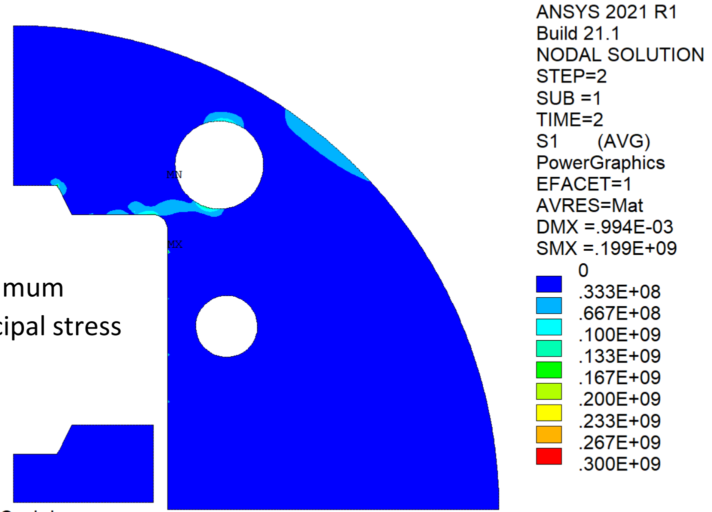
Mechanical Analysis

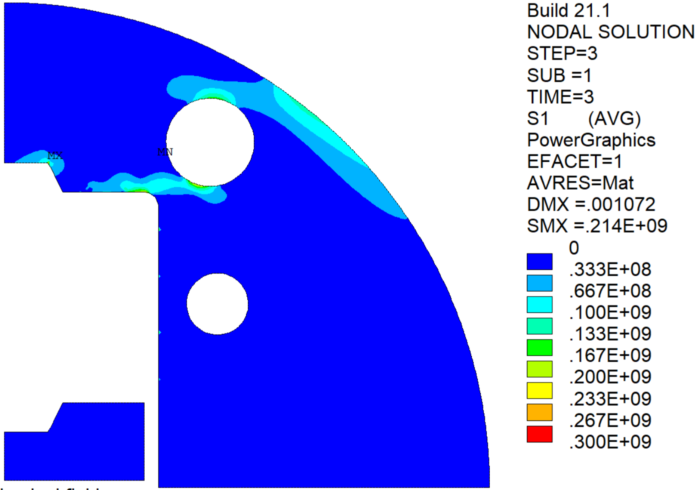
Maximum principal stress



Keys



Cool-down



Nominal field

Mechanical Analysis

14 T operation

Stress on coils: **123 MPa on corners,** other else < 100 MPa

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

Von-Mises