Design, manufacturing and testing of a high-field 2 + 3T MgB_2 dry magnet demonstrator

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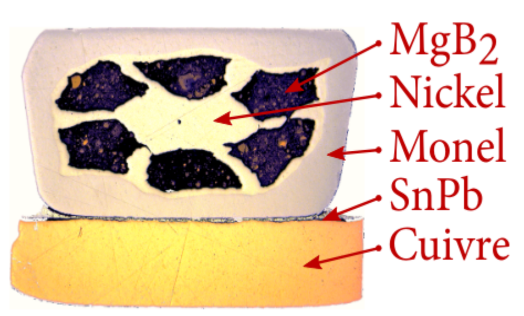
Context and goals

- Helium price is increasing and experiences crisis
  → Develop a dry magnet prototype with resistive junctions
  → Develop efficient thermalization apparatus for a conduction cooled-magnet and the junctions
- High field MgB_2 magnet of 5 T must be developped to compete to NbTi
  → Generate 2T in a 3T background field (produced by a homogeneous NbTi magnet named H0)
  → Demonstrate good behavior of commercial conductors during all the manufacturing stages (i.e winding on small radius)

Conductor properties

Columbus PIT C-doped R&W *ex-situ* wire



Parameters	Value	Unit
Cross-section	2 × 1	mm^2
Copper strip (stab.)	2 × 0.5	mm^2
Filling-factor	26	%
Ni sheath	30	%
Monel clad	44	%
Number of filaments	6	

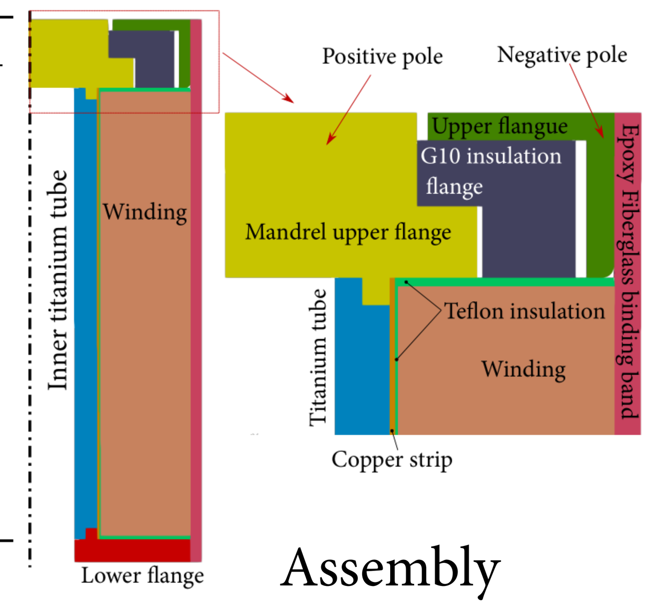
Strain limit

Critical current degradation evidenced after $\varepsilon_c = 0.4\,\%$ under bending for a development version of the prototype's conductor

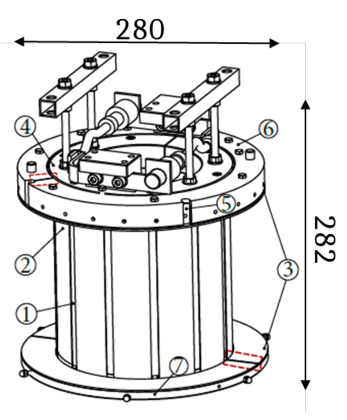
Prototype characteristics

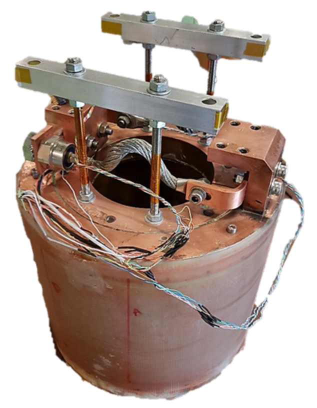
Parameters	Value	Unit
Internal radius	100	mm
External radius	140	mm
Height	282	mm
Weight	55	kg
Number of layers	24	–
Number of turns per layers	87.9	–
Nomber of turns	2112	–
Conductor total length	1.6	km
Inductance	0.71	H
Nominal temperature	10	K
Nominal current	200	A
Nominal current density	57	A/mm^2
Nominal stored energy	17 972	J
Nominal center field	1.8	T
Field on conductor	2.1	T

Parameters

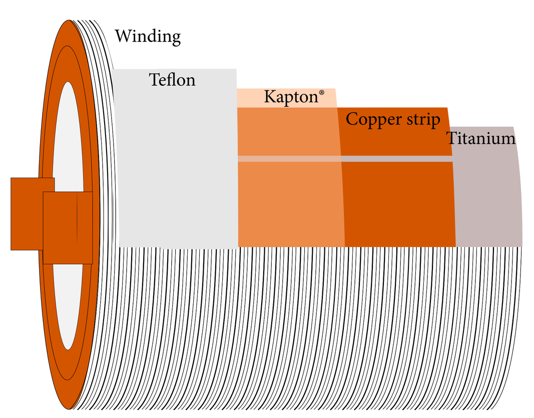


Assembly





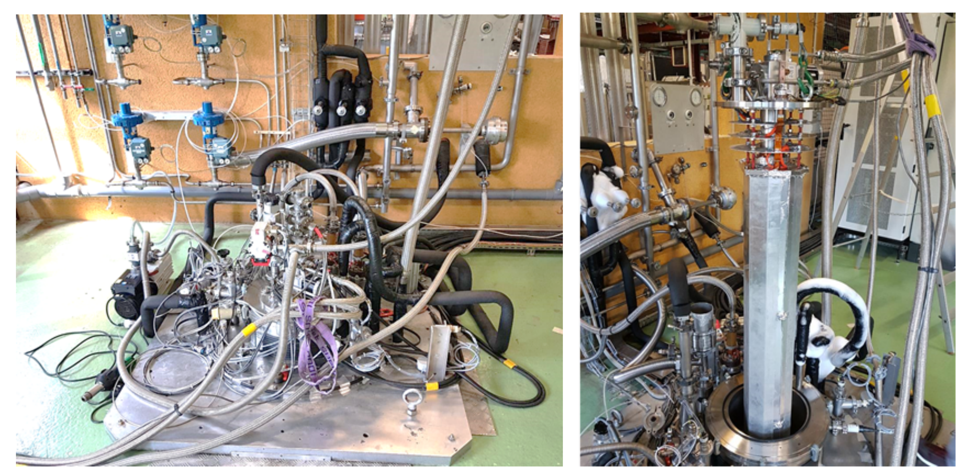
Geometry



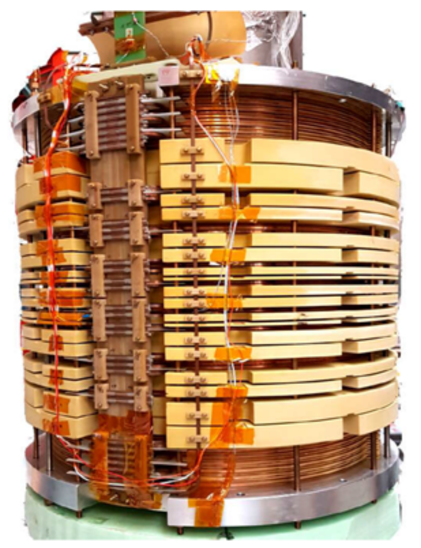
Mandrel layers

Test station characteristics

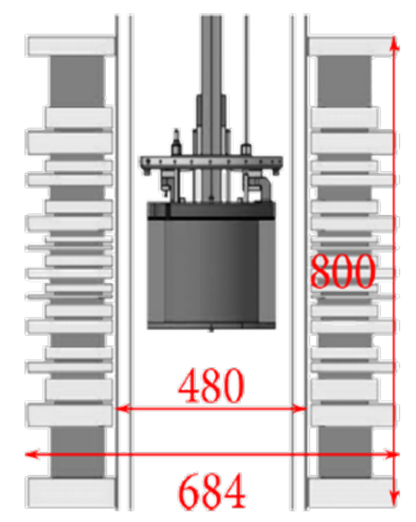
- Temperature of test : 5K → 40K (cryocooler)
- Temperature measured by 3 cernox placed inside the pad and in the lower flange of the prototype
- Homogeneous 3T background field produced by H0
- MgB_2 samples of around 1 m length can also be tested



View of the test station



H0 (Bmax = 3T)



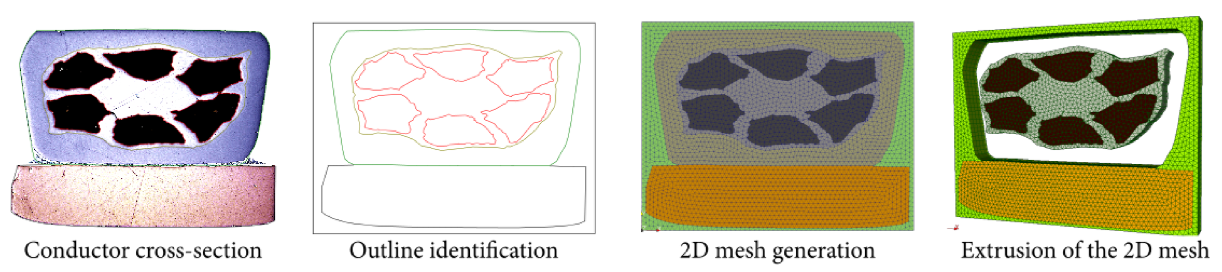
H0 dimensions

Prototype

Conductor homogeneization

Meshing (Salome software)

- ✓ Only need cross-section picture and Salome
- ✓ Can mesh precise geometry and easy to implement



Procedure (Cast3M)

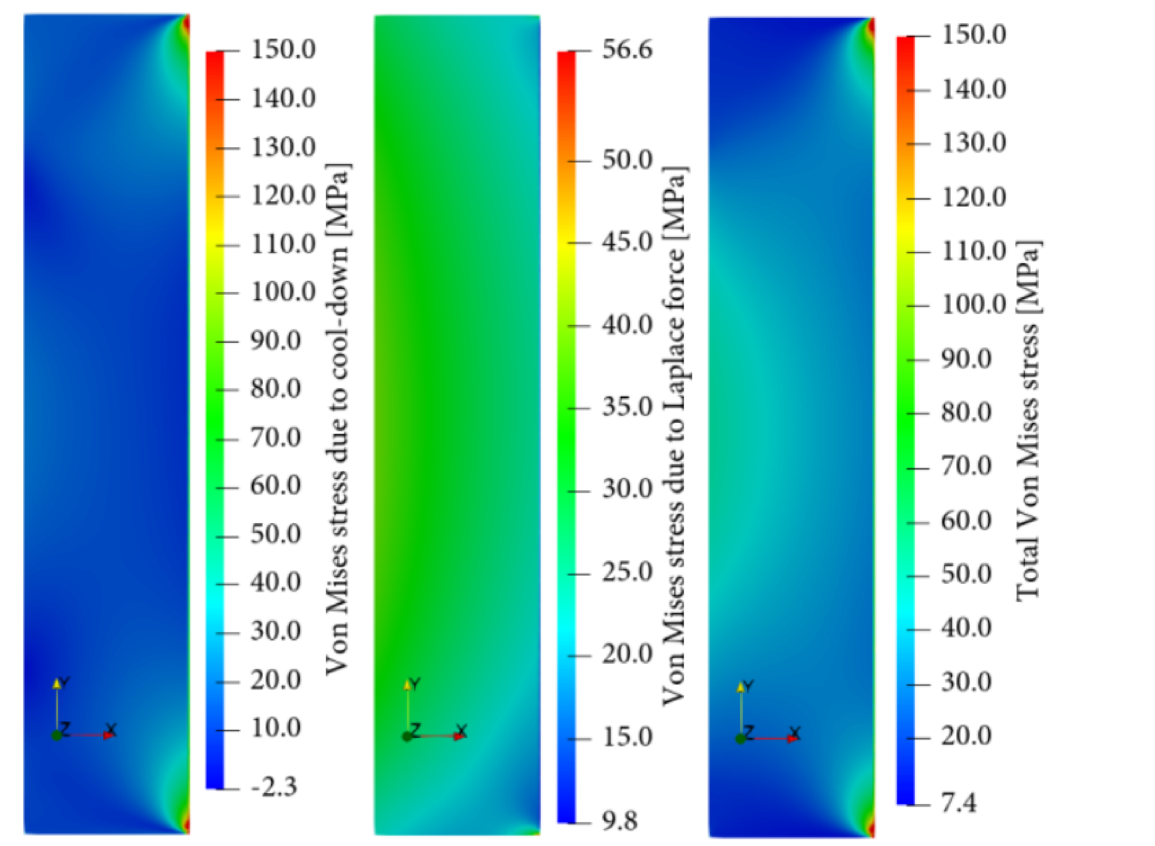
Mechanical properties (Young modulii, shear modulii and Poisson ratios in all directions) homogenized by a Cast3M procedure named Keff with periodical boundary conditions

- ✓ Periodical boundary condition accurate for winding
- ✓ Fast computation even for very fine mesh (of the order of minutes for very fine mesh)

Von Mises equivalent stress

Modelisation input

- $I_{des} = 225$ A ($J_e = 64$ A/mm^2) generating with H0 combined, a center field of 5 T (5.39 T on the conductor). Cooling is calculated for a temperature from 293 K to 4 K
- Slipping of the winding is made possible at the border between the teflon insulation and the winding



Von Mises stress [MPa]		
	Winding	Corners
Cooling	10 – 20	420
Energizing	30	–
Total	7 – 50	–

Von Mises equivalent strain

$$\varepsilon_{eq} = \frac{1}{1+\nu_{xy}} \sqrt{\frac{(\varepsilon_x - \varepsilon_y)^2 + (\varepsilon_y - \varepsilon_z)^2 + (\varepsilon_z - \varepsilon_x)^2}{2}}$$

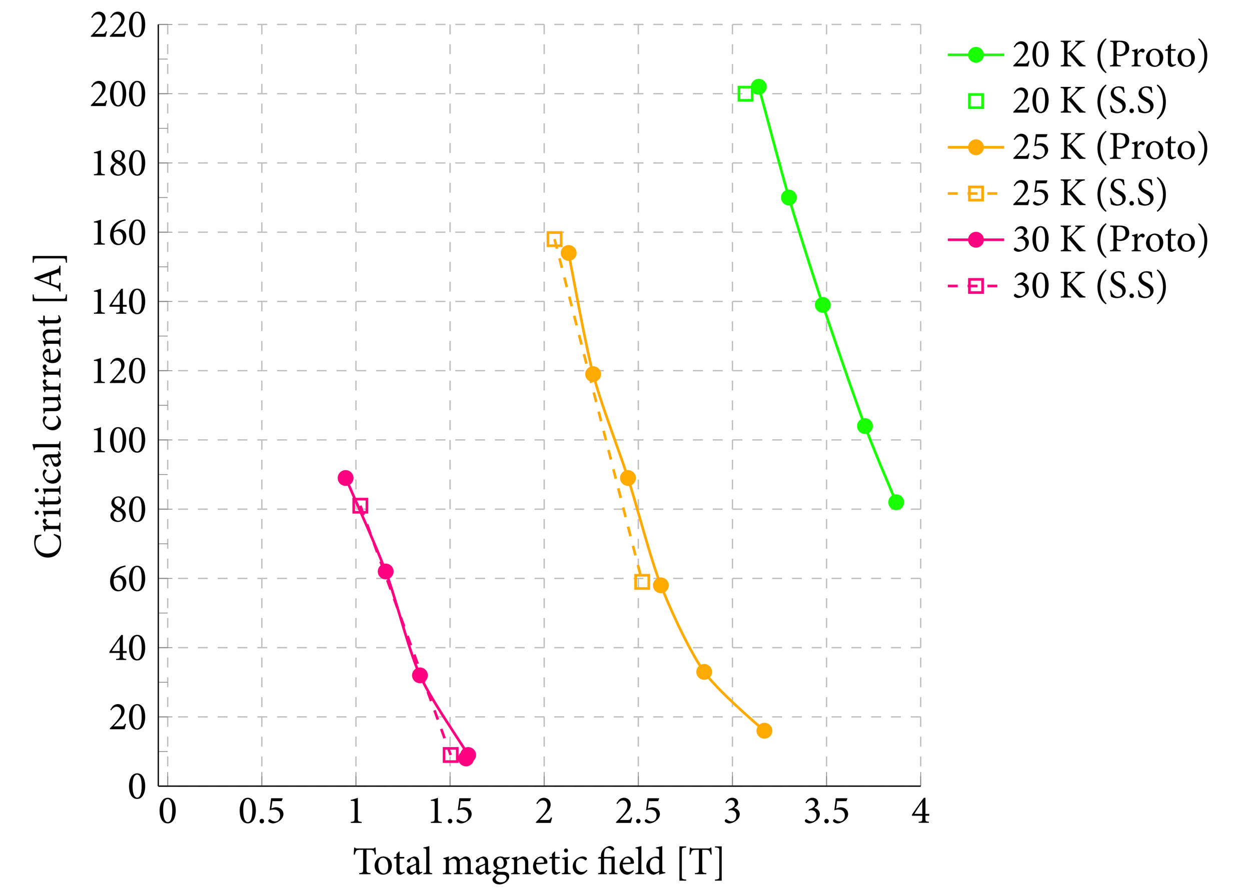
Von Mises equivalent strain ε_{eq} [%]		
	Winding	Corners
Cooling	0.019	0.033
Energizing	0.034	
Total	0.048	0.053

Conclusion

$\varepsilon_{eq} < 0.4\,\%$ in the winding and in the corner therefore, the conductor does not experience degradation during cooling and energizing

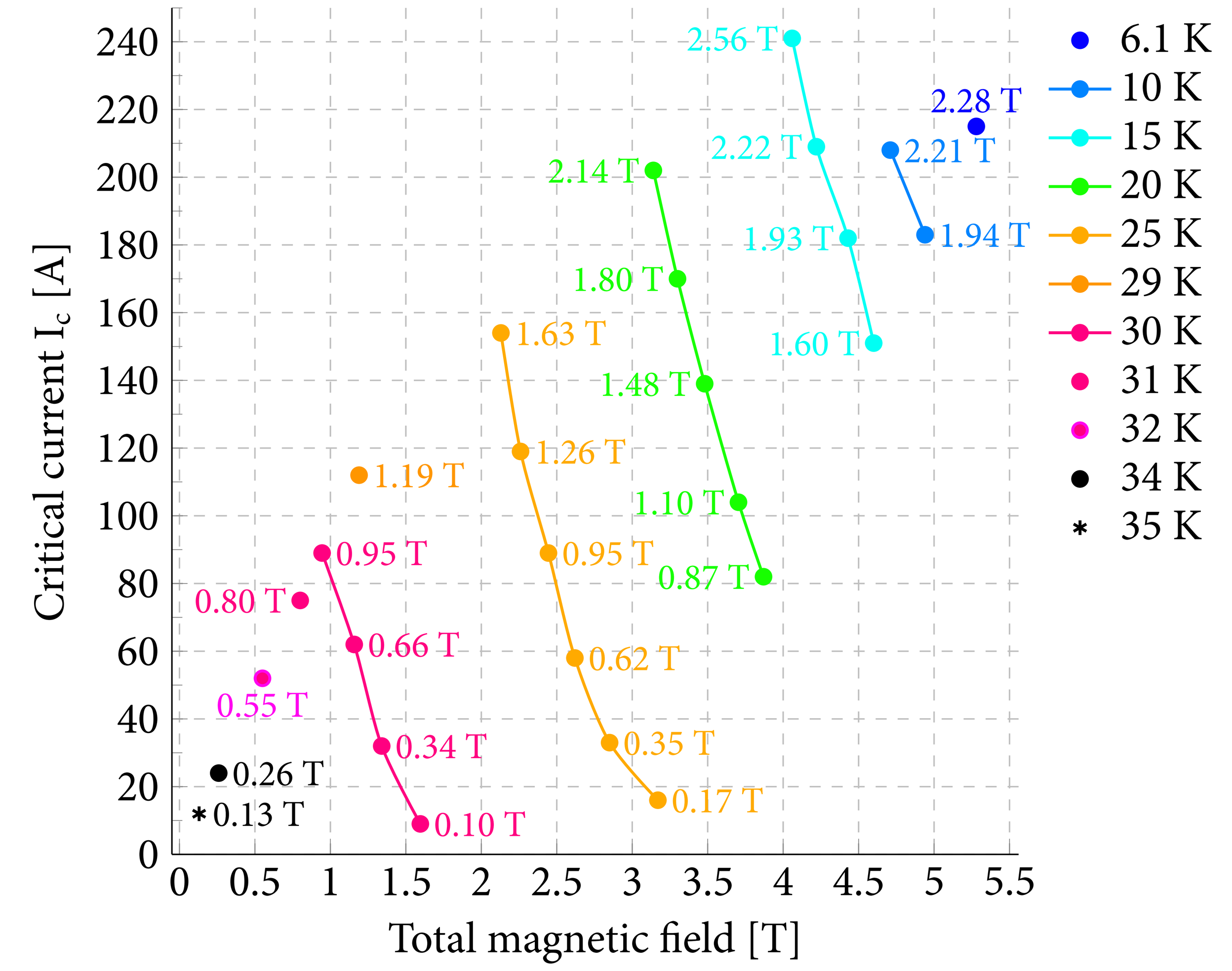
Superconducting performance

Comparison of two sets of measurements : prototype and short sample (S.S)



- ✓ No degradation during the construction phases and testing of the prototype

Prototype performances: field on the conductor and field generated by prototype alone (in parentheses)



Conclusion

- ✓ Fast and accurate (yet to be validated by mechanical test) homogeneization method permitted to predict the mechanical behavior of the conductor during cool down and energizing
- ✓ The construction procedure is validated since no degradation was evidenced and the magnet successfully reached the target 5 T under 10 K